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AID BOOK
TO ENGINEERING ENTERPRISE

THIRD EDITION

EWING MATHESON

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of the
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AID BOOK

TO

ENGINEERING ENTERPRISE.

AID BOOK

TO

ENGINEERING ENTERPRISE.

BY

EWING MATHESON,

M. INST. C.E.

THIRD EDITION, REVISED.

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PREFACE
TO
THE THIRD EDITION.

THE continual demand for this book induces the author to publish a new edition. Owing to the rapid advance of engineering science, which has made so many new methods and machines available, a thorough revision has been necessary, and some of the chapters have been almost entirely re-written.

The original purpose and plan of the book remain. In the First Part the author endeavours to classify and link together the technical and economic conditions which determine the success or failure of Public Works and Engineering ventures, and in doing this, he enumerates those preliminary particulars on which designs and estimates of cost can alone be framed. Considering how numerous are the branches of engineering science, and how great the variety of works arising out of them, it is obvious that in the compass of a single volume it would be impossible, even if the author presumed to attempt it, to deal exhaustively with them. But as an aid to those who may be interested in the projecting of engineering enterprises, an investigation of the preliminary points above referred to may be possible and useful, especially where promoters of new undertakings abroad seek the assistance of British engineers, capitalists, or contractors—with whom it is important to have a clear common understanding.

In the Second Part attention is drawn to the various modes of forming contracts, and to the conditions necessary to the choice and purchase of engineering material, these particulars being given specially as an aid to Foreign and Colonial transactions, in which disappointment often arises from want of a full understanding between those concerned.

LONDON: *September 1898.*

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AID BOOK

TO

ENGINEERING ENTERPRISE.

CHAPTER I.

ENGINEERING ENTERPRISE IN GREAT BRITAIN. PARLIAMENTARY PROCEDURE FOR RAILWAYS. BRITISH AND FOREIGN LEGISLATION COMPARED.

British usage.

ALTHOUGH it is the purpose in the following pages to treat more of foreign than of home enterprises, it may be convenient first to summarise such of the British usages in these matters as may serve as a basis of comparison elsewhere. For the inception of engineering undertakings, there have grown up, through long experience, regulations and conditions, many of which are now embodied in precise codes of law and rules of procedure. These rules may be of use even to those outside Great Britain who have to initiate large works, and who may adopt as equitable some of the principles, if not the precise details, of English practice. On the other hand, unless the differences of circumstance, locality, and security are properly apprehended, foreign enterprises and estimates of profit based on the success of similar undertakings in Great Britain will be found to fail in practice.

Foreign undertakings.

While the tendency in England during the present century has been mainly in the direction of free-trade, restrictions of an entirely different kind have at the same time been growing up, of which the Mines Regulations Acts, the Education Acts, the Factory Acts, and

Legislative restrictions. the Compensation for Accidents Act, may be cited as examples. Although these Acts have been framed in the interests of the public, they none the less enhance the cost of coal, iron, and machinery, and have weighted many manufacturing interests in the competition with those foreign rivals to whom such restrictions are unknown. There are other laws which affect engineers and control their designs. Among these are the Board of Trade regulations for railways, steamships and electric lighting, the bye-laws of river conservators and harbour commissioners, to all of which conformity is required. **Voluntary restrictions.** There are also the rules of voluntary societies, which are in effect equally binding. Lloyd's rules demand, as a condition of registry, certain dimensions and qualities of vessels; fire-insurance companies have rules as to buildings, and for the protection of electric conductors; steam-boiler associations, a certain margin of strength in boilers; and to all these, engineers have to conform to an extent that is not customary in regard to similar matters abroad.

But while engineering projects are thus controlled by legislative, municipal, and voluntary enactments, equally striking is the contrast between British and foreign usage in the respect paid to vested interests. In an old-established and crowded country like England, large engineering enterprises generally involve considerable interference with existing rights, **Vested interests.** and can only be commenced and carried on by the authority of Parliament. Although during the fifty years following the introduction of railways the system of legislation in regard to these and kindred enterprises has been altered, simplified, and improved, yet from the first conception of a new undertaking, every step in advance is fenced round with elaborate precautions for the protection of those affected, the interests most carefully guarded **Landowners and occupiers.** being those of the owners, lessees and occupiers of land, who, if compelled to sell, become entitled to the utmost value of their property, and to compensation for incidental loss by severance. The nature of the precautions adopted may be exemplified by stating the prescribed course of parliamentary procedure in the case of a proposed new railway; rules of similar import being applicable to other large undertakings.

Railway schemes. Local promoters, capitalists, or others who have determined on a new railway, generally, as a first step subscribe among themselves for the preliminary expenses, or ask subscriptions for the purpose from **Preliminaries.** those most interested, or even at this early stage invite subscriptions for shares. The opinion of an engineer is asked as to the feasibility and cost of the new line, and the engineer makes a preliminary survey of the country with trial sections, marking one or more possible routes on the Ordnance map. If the information thus obtained proves sufficiently favourable to warrant further action, a certain route is adopted, the preliminary surveys and estimates of cost are revised, and plans and sections on a scale prescribed by the Standing Orders of both Houses of Parliament, of not less than four inches to the mile, and a vertical scale of not less than one inch to 100 feet, are prepared, showing the line of railway. The existing Ordnance maps are often adopted, but it is only where the Ordnance map of the district in question is drawn up to four inches to the mile that such a small scale is adopted. All buildings have to be drawn to a scale of not less than one inch to 400 feet, so that where a smaller scale is used for the general plan, separate enlarged details have to be furnished. As it would be impossible at this early stage to define exactly the width and extent of land required, "limits of deviation" of 100 yards on each side of the line are delineated, and within these limits the engineer will be permitted, if the railway is authorised, to construct the necessary works. A book of reference to the plans has also to be prepared, containing the names of all owners, lessees, and occupiers of land or houses within the limits of deviation.

Ordnance maps.

Plans and sections.

Limits of deviation.

Book of reference.

The plans, sections, and book of reference are generally printed, and copies of those portions affecting counties, towns, or parishes are deposited in each case with the clerk of the peace, parish-clerk, or other local functionary. Notices in a prescribed form have also to be served on the owners, lessees, and occupiers whose land is on the line, or is comprised within the limits of deviation informing them of what particular property may be taken from them, and where the plans and book of reference may be inspected. Moreover, as part of such notice, is a request that an answer be sent back, announcing assent, neutrality, or dissent with reference to the proposed undertaking, the answers having to be embodied by the promoters in a schedule for Parliament. Notices have also to be inserted as advertisements in one newspaper in each county through which the line passes, and in the *London Gazette*, and, if the railway touches more than one county, in one London newspaper also. With the exception of the *Gazette*, where one insertion only is needed, all these advertisements must appear twice, namely, once in each of two successive weeks, with an interval of six clear days between the

Notices.

Advertised notices.

publications, in October or November, no advertisement appearing later than November 27.

Private Bills. The project has to be set forth in what is termed a "Private Bill," in contradistinction to the "Public Bills," which relate to public or imperial measures; and as the promoters seek, by obtaining the sanction of the Legislature to their Bill, to transform it into an Act of Parliament (which is the term applied after it has passed both Houses, and received the Royal assent), authorising compulsory purchases and other interference with the rights of others, it is necessary to include in the Bill every power requisite for this purpose. A copy of the Bill, together with a copy of the *Gazette* notice, plans, sections, estimates, book of reference, and Ordnance map, have also to be deposited in the Private Bill Office of the House of Commons, with the Clerk of the Parliaments for the House of Lords, at the office of the Board of Trade, at the Treasury, and at the General Post Office, and also—where tidal waters are affected by bridges, embankments, or otherwise—with the Harbour Department of the Board of Trade, and, in certain cases, at other Government Departments. **Minister of Public Works.** There is no Minister of Public Works, so called, in England; but many of the functions generally entrusted to such a Minister are in England performed by the Board of Trade, where **Government engineers.** there are permanent official engineers to examine the plans, to see that nothing in the laying out of the railway is prejudicial to the safety of the public. The official inquiry is at this stage confined to such matters as the crossing of roads and the arrangement of junctions; but if the railway be authorised and made, a stricter inspection of details takes place before the opening of the line for passenger traffic is permitted. For there have grown up during the years of railway-making, certain standards of fitness, which, in the interests of the public, are enforced—the strength of bridges, the length of stations, and the arrangement of signals being examples of the numerous points upon which conformity to rules is required.

As some bar to idle or vexatious applications for Private Acts, a **Caution-money.** *See also page 37.* deposit of money, which may be termed "caution-money," or approved security, amounting for railways to 5 per cent. on the estimated cost of the undertaking, has to be made at a public office—that of the Chancery Division of the High Court of Justice. Formerly this money was forfeited if, in case the railway was sanctioned, it was not completed within the time prescribed by the Act, or within any extension of time granted by a new Act, or unless the undertaking

Abandonment.

See "PARLIAMENTARY DEPOSITS ACT," 1892.

was, by permission of Parliament, abandoned. This rule as to forfeiture has been relaxed, but even where abandonment is permitted, and the deposit returned, landowners are allowed compensation for any injury they may have sustained by the operation of the Act, such compensation being made to them out of the deposit-money before repayment to the promoters.

Standing Orders.

Examiners.

Opposition.

Errors or omissions.

The Bill, plans, estimates, and notices having been advertised and deposited, as just described, on or before certain fixed days in the months of November and December, and the caution-money deposited in January, the application to Parliament is fairly launched, and must be proceeded with according to fixed rules, entitled "Standing Orders," in the session of Parliament commencing in February. The number of Private Bills presented to Parliament is so great, and the questions involved so numerous and complicated, that it has become more and more necessary that the preliminary investigation should be concluded before the measures come to the stage of discussion on their merits. Two permanent examiners are therefore appointed, whose duty it is to examine every Bill, and to decide whether the rules of procedure above described, and which are set forth in the Standing Orders, have been complied with, and to report thereon to the special committees deputed to receive them. While the Bill is before the examiners, the promoters are required to attend to prove that they have satisfied the prescribed conditions. This stage in the proceedings affords the first opportunity for those who desire to oppose the Bill to bring forward their objection that the Standing Orders of Parliament have not been complied with in respect to the Bill. Landowners, rival companies, and others may, and frequently do, attend by agent to argue, not on the merits of the undertaking, but that the preliminary conditions or Standing Orders have not been complied with. Opposition at this stage is not, however, confined to those whose interests may be directly affected, but, as the regulations of Standing Orders have been framed in the public interests, anyone may attend and draw attention to errors or omissions in regard to compliance, other than errors directly affecting owners, lessees, or occupiers of land, which can only be noticed by those directly interested in the land. As from time to time there are modifications in the Standing Orders, a new edition is published every year.

There are Parliamentary agents—often solicitors—whose special business it is to manage Private Bills, and who support or oppose them as the interests of their clients may require. **Examiners' reports.** If the examiners report that the Standing Orders have not been complied with, the Committee of each House on Standing Orders appointed each session, who receive the report, have to consider whether there be any reason why compliance should be dispensed with, and whether in their opinion the parties to the new undertaking should be allowed to proceed with their Bill or any portion of it, and, if so, under what conditions. **Exemptions.** Where exemption is granted, it is generally because the omissions have been trivial, or because the public convenience would suffer by the stoppage of the Bill. If Standing Orders have not been complied with, and if no exemption from compliance is accorded, the Bill fails, and can proceed no further, although the promoters may start again in the next session of Parliament, if they choose. **First reading.** If the report is in its favour, the Bill is read a first time in that of the two Houses to which it is presented. All Bills, public and private, have to be presented to and sanctioned by both Houses of Parliament, and have finally to receive the Royal assent, the Private Bills for railways and similar undertakings being initiated in one or other House, as may be arranged by the authority of the two Houses. At the commencement of every session each House appoints, by means of a "Committee of Selection," committees of its members to consider and report upon Private Bills classified according to their kind. Those Bills which have passed the ordeal of "Standing Orders" are generally read a first and second time without opposition, and are at once referred to one of the committees for consideration. **Adverse petitions.** Those who intend now to oppose the Bill on the merits must present their petitions within a limited time after the first reading (in the Lords after the second reading). **Locus standi.** The promoters may object to the *locus standi*, or right to be heard, of the petitioners, and—if the Bill be in the Commons—the **Referees.** petitions and objections are referred to other officials, called the Court of Referees, who decide the point whether the petitioners are or are not to be heard; and their decision on this point is final.

Second reading. In Public Bills the discussion and contest on the principles of the measure take place on the second reading, before the Bill is referred to a committee, and if a Private Bill is one of very great importance, it may also be discussed at this stage, and stopped if a majority so wills it. But this occurs rarely with Private Bills, which, if they have passed "Standing Orders," are read a second time and referred to a committee almost as a matter of course. **Procedure in Committee.** The committee, having before them the plans and sections, also large maps or diagrams, hear the evidence brought forward by the promoters and their counsel or agents in favour of the project. The opponents of the Bill appear here also, and by their counsel or agents argue, and by their witnesses attempt to prove, that the Bill should be rejected, the principal pleas generally being that the undertaking is not really needed in the interests of the public; that it will interfere unjustly with rival undertakings, with land, property, or other existing interests; that the engineering details are defective; and that the work cannot be constructed for the amount of the estimate. In arguing for or against the Bill, the "Preamble," which is equivalent to the "Declaration of Public Utility" usual in foreign schemes, is first considered, for Parliamentary powers are held to be in restriction of the liberty of the subject, and those who seek them have the onus thrown on them of proving the necessity. If it can be shown that the reasons adduced for the project are not correct or sufficient, the committee may determine that the preamble is not proved, and so report to the House; such a report having generally the effect of terminating the Bill. If, however, the preamble be proved, then the Bill is discussed, and such clauses as are obnoxious to the opponents contested step by step. In the interests of landowners, of rival companies, or the public, the conditions are often modified or new conditions imposed, so that if the Bill succeeds in obtaining the approval of the committee, it frequently does so in a somewhat different state from that in which it was first presented for examination. The Bill is then reported to the House as approved, the report is considered, and the Bill is then read a third time and passed.

Opposition.

Adverse allegations.

Preamble.

Discussion of clauses.

Third reading.

Having been thus passed in one House, the Bill has to be presented to the other, and to pass through the same ordeal of committee and approval, although there are slight differences in the procedure. For instance, objections to the *locus standi* of petitioners are, in the Lords, not considered by a Court of Referees, as in the Commons, but by the committee on the Bill when it meets. The verdict of its committee is by each House almost always adopted; but if the Bill is one which excites much interest, it is sometimes discussed in the full House, and decided by the vote of the majority. In such case a Bill may, by a resolution of the House, be referred back to the committee, or if the importance of the matter warrant it, be considered in a committee of the whole House, and if a majority so will it, pass, in spite of the previous adverse determination of the smaller committee. Although the Bill may be opposed when it is first pre-

Lords and Commons.

sented, and at each of the three readings, and at the consideration of the committee's report, and at the final passing, the usual time for discussion and voting, if such take place at all in the House itself, is at the second reading. Opposition after the second reading and after passing the committee is very rare, and in the vast majority of cases the procedure beyond this point is only formal. If the Bill fails in either House it is lost, but if it be passed by both Houses of the Legislature it, as a matter of course, receives the Royal assent, and, as an "Act of Parliament," becomes law, the refusal of the Royal assent to Private Bills being practically unknown.

Opposition rare after second reading.

Royal assent.

It is not intended here to enumerate all the conditions which must be fulfilled, but the foregoing is a brief summary of the process of legislation on railways in Great Britain. For Harbours, Docks, Tramways, Waterworks, and other large engineering enterprises, the procedure is very similar, special conditions and rules as found necessary by experience for these particular undertakings having been adopted and embodied in the Standing Orders. Certain kinds of undertakings—of which Water, Harbour, and Sewage Works; Parks, Embankments, and Piers, may be cited as examples—are often projected by Corporate bodies, to whom certain facilities are granted in the matter of procedure. Thus, when a Private Act is promoted by Commissioners, a Corporation, or others in the public interests, the money for the undertaking being raised by public rates, caution-money is not required as in those cases where undertakings are constituted for the pecuniary profit of shareholders or others. The number of Private Acts applied for in this way has tended to increase. Where a Bill is promoted or opposed by a Town Council or other representative body, ratepayers or others cannot, unless they have personal interests, oppose the view of their representatives, even though they form part of a strong minority of the citizens opposed to the action of their officials.

Facilities granted to Corporations.

Parliamentary procedure is always expensive, and where the progress of private Bills is opposed, the cost of obtaining an Act is sometimes enormous. In the case of Railway Bills which have been keenly contested, the cost has in some rare notable instances even exceeded £5000 per mile; excessive expenditure appearing in this way at its worst where the expenses have to be divided over a short mileage. Even where there is no opposition, the mere routine expenses are so considerable, and bear so high a proportion to the

Excessive costs.

entire cost of small undertakings, as to stop the progress of those that require legislative sanction. To meet cases of this sort, and for undertakings of which Gasworks or Waterworks in small towns, where there is no great interference with private interests, may be quoted as examples, the Legislature permits an easier process than that just described. "Provisional Orders of the Board of Trade," authorising such undertakings, are granted, if, on inquiry by responsible officials, the scheme appears equitable and desirable. Plans and particulars have to be deposited by the promoters at the Board of Trade in the month of November, somewhat in the same way as just described for Private Bills, but in a simpler and less expensive manner, and by the spring of the following year the examination of the scheme is concluded. About the month of June or July in every session a special Bill is promoted by the Board of Trade for confirming Provisional Orders, and in this Bill are included all the schemes which have been examined and approved since November, the expenses attendant on the passing of the necessary Act being borne by the Government. Sufficient opportunities, which need not be stated here, are afforded to those affected by any of the schemes, to oppose them, but almost invariably the schemes recommended by the Board of Trade are confirmed by Parliament, and are included in the general confirmatory Act. The Board of Trade decides in each case, when it is presented to them, whether the undertaking is one which may be properly sanctioned by Provisional Orders, and, if not, may at their discretion transfer the matter to a committee of Parliament for examination and further progress as an ordinary Private Bill; but the tendency in recent years has been to extend the use of this form of legislation in regard to engineering enterprises.

Provisional Orders of Board of Trade.

Confirmatory Act.

See also page 76.

Light Railways Act.

Other Legislative enactments have been framed to facilitate the making of small railways, where the landowners and other persons beneficially interested all consent; and in such a case the Board of Trade (which is supposed to examine and amend the scheme in the interests of the public) grants a certificate permitting the railway to be made. The advantages expected from these facilities have not, however, been realised, for it has been found impossible in the great majority of cases to obtain the necessary unanimous consent. While, however, this system has been found inoperative in England, where vested interests are so numerous, it may be suitable and beneficial in a new or pastoral country where but few persons are interested in the land.

Railways Construction Facilities Act.

Before leaving this subject to deal with enterprises of various kinds in foreign countries it may not be out of place to refer shortly to some characteristics of the British procedure which appear most significant. While public law-making may be, and often is, at the discretion or caprice of Ministers or Parliament, of a sudden and unexpected character, legislation for private undertakings cannot be so. All private measures are, by their publication, submitted, as has been seen, to criticism and comment long before Parliament meets, so that no one can complain that he or his class are surprised by any Private Act. The Standing Orders of both Houses are framed to prevent hasty legislation, requiring as they do, and as has been described in the preceding pages, that in order that Bills may be discussed in Parliament between February and August in one year, the notices shall have been given, and advertisements shall have appeared, in October or November of the year previous. In all these matters of procedure improvements have been made, which not only tend to the protection of private interests, but render the work of promoters easier. Not the least of the improvements has been the assimilation of the rules of the two Houses of Parliament, and the reference of all preliminary questions to the same set of permanent officials. In the opinion of many promoters, parliamentary agents, and others specially qualified to judge, further progress in this direction is needed. Joint committees of the two Houses are even now sometimes appointed to settle such questions as the amalgamation of railways, and if by some one tribunal of this sort all Private Bills could be discussed, the enormous expense now occasioned by the double inquiry would be avoided. But there is a not unnatural jealousy in both Houses concerning any proposed abandonment of their separate powers, and sooner than relinquish such powers directly, it is probable, if an increasing press of business force a change, that more of the real work of investigating will be left in the hands of the permanent paid officials already referred to. As so much of the time of Parliament is occupied with private legislation, it is also suggested that these questions be dealt with by local tribunals, or in other words by a species of "home rule." On the other hand, though time and expense might be so saved, it is questionable if so much impartiality would be found.

British procedure reviewed.

Procedure simplified.

Joint committees.

For while parliamentary committees do not form perfect tribunals, no one in recent times has charged them with wilful unfairness or corruption. Happily, in Great Britain, the public men who in both Houses make up the committees are, with very rare exceptions, of such a character as to command respect for impartiality, ability, and disinterestedness. It is doubtful whether any court could be constituted, even in London, more satisfactory to business men than a committee of Peers, presided over by an experienced chairman. It is equally doubtful whether there could be any courts freer from suspicion than the average committees both of Lords and Commons, who administer a system of procedure which has grown up to suit the special questions brought under their control.

Fairness of English system.

The further procedure in regard to British enterprises is too well known to need much description. A municipality, a company of capitalists, or others who have determined on some undertaking, and who have obtained their Act of Parliament as described in the foregoing pages, then procure from their engineer such further plans and specifications as will enable contractors to estimate the cost of the work, and upon such a basis tenders are invited. The competition may be limited to a few contractors who are known as capable by the engineer; or the competition may be thrown open by advertisement to all who choose to tender. That offer having been accepted which is considered to be the most favourable, the works are then commenced, and the contractor is paid in money or other values according to the terms of his agreement. The contract may or may not prove profitable: that is a matter for the contractor. The work after its completion may or may not prove remunerative: that is a matter for those who pay for it; but for most works of public importance the two aspects of the case are kept quite distinct. The reasons which have prompted contractors in England occasionally to accept payment in shares, obligations, or something other than money, are various. Sometimes it is sheer speculation, and the temptation of the nominally high prices which in such cases are generally obtained. As regards railways, however, and some other classes of works, the special regulations usually contained in the authorising Acts of Parliament with regard to the issue of debentures, have been the chief cause of such ventures. In most cases, debentures cannot be legally issued until the whole of the share capital has been subscribed, and a certain proportion—usually one-half—paid up; and in more recent railway legislation the stringency of this condition has been increased by the provision that not only must one-half the share capital be paid up, but that such half shall include at least

Tenders invited.

Letting of contract.

Payment in shares.

Debentures.

Debenture issue limited.

20 per cent. of each particular share before any issue of debentures can take place.

See also page 44.

It frequently happens that difficulty is experienced in obtaining subscriptions from the public for shares in new undertakings, the revenue from which is largely a matter of conjecture. In these circumstances the contractor—who may probably have taken the initiative in obtaining Parliamentary powers, and is principally responsible for all expenses up to the passing of the Act—subscribes, either personally or by his nominees, for whatever portion of the shares is not otherwise applied for, the money paid by him in respect of such shares being, perhaps, almost immediately returned to him as payment for work done. The issue of the debentures, which may be nearly sufficient in amount to defray the whole of the contractor's real outlay, is thus rendered legal; and, as a rule, investors are more ready to lend money on such debentures, and bankers to make advances, than upon ordinary shares. There have been enough successful ventures of this kind on the part of contractors, especially at times when money has been plentiful or speculation rife, to tempt similar action again, and railways so made have been numerous enough to be classed as "contractors' lines." But there have been also many disastrous failures, and such methods of promoting engineering enterprise are often looked upon in England with disfavour. It would certainly be erroneous to consider such arrangements as usual or approved. In respect to debentures and their relation to shares, there is the evident difference between the British system and that obtaining in the United States, where the bonds generally form almost the whole real capital of the undertaking.

Contractors lines.

See also page 41.

See BANKERS, *page* 43.

Failure of contractor.

There is a growing tendency in Great Britain to widen the scope of municipal enterprise, and to construct public works out of public funds rather than at the expense of private capitalists. Not only gas, water, and drainage works are undertaken by corporations, but in many cities electric lighting and tramways also. It is necessary, however, to obtain the special sanction of the Board of Trade for the loans raised for these purposes, and stringent conditions are imposed in regard to the repayment within a specified term of years. A still wider field has been opened by the modern institution of County Councils who, acting for a larger area than the older municipal bodies, are likely to undertake wider duties. Water supply schemes for large districts, light railways for agricultural purposes, the regulation of rivers, and the transmission of power,

Municipal enterprise.

Corporation works.

County Councils.

are examples of enterprises likely to be undertaken out of public funds.

Foreign undertakings.

It is not the present purpose to refer further to what is customary in Great Britain. Those who are concerned in such matters know what to do, or have ample means at hand for obtaining information and advice. In regard to very many foreign undertakings the course is not so clear, and to these cases attention will be now directed. And as general principles of prudence are not confined to localities, what follows may in many instances apply equally well to home enterprises.

Foreign and British procedure compared.

All countries, according to their civilisation and the usages of the people, have, of necessity, laws and customs regulating those engineering works which affect public or private interests. The extent to which such enterprises require control depends of course everywhere on their nature and magnitude, and it has been shown how fully existing interests are studied in Great Britain; but there is one marked difference between the laws which regulate these matters and those which prevail in the foreign countries which most require British aid. In Great Britain there is an almost unlimited supply of capital ready for any enterprise which appears profitable, and if, for instance, a district is in manifest need of a railway, or a town of waterworks, there are eager engineers, capitalists, and contractors to design and construct the works. Hence for the vast majority of works the Government of the country has no need to initiate or even to encourage enterprise, and so far as it interferes at all in such matters, does so only to regulate, control, or even forbid. In European countries of the first rank there are codes of laws and official regulations as strict and as well defined as in Great Britain. The continental Governments, in regard to railways and other large engineering works, may be said generally to exercise more control in the authorisation and management than in England. In these countries many of the railways are under State control, the State aids them by national funds, and promotes legislation which has in view the still further conversion of these large engineering undertakings into national property. Competition is not permitted to the same extent as in England, and there is everywhere more of what may be termed paternal control. Many of the earlier continental railways were constructed by English engineers and contractors, but there is now more home capital and skill available.

State aid.

Colonial public works.

In those British Colonies which have their own Legislatures, the example of the parent country has been largely followed in the forms of parliamentary procedure by which new undertakings are sanctioned. But the Colonial Parliaments and Governments have much more to do than in England with the initiation of new works, and have also to assist in providing the necessary funds. This does not arise from any lack of enterprise among the colonists, but from lack of cheap money. There is not in the Colonies the same large class of private investors with available capital, and content with a safe three or four per cent. interest; and as those who have money in the Colonies can employ it actively in profitable undertakings, the current rate of interest for ordinary commercial transactions is always much higher than in England. Hence people are glad to take advantage of the abundant wealth in England, and to borrow, by means of their Government and Legislature, at a much lower rate than would otherwise be possible. The money is generally raised in the shape of a loan for which the credit of the Colony is absolutely and unconditionally pledged; and investors in England, who would not venture to embark their capital in a distant country in railways or other speculative enterprises beyond their control, will trust to the engagements of the Government who have invited the loan. Happily, the good credit of Great Britain is shared by her Colonies, which can borrow at from three and a-half to four per cent.

Lack of capital in the Colonies.

Colonial loans.

See LOANS, *page* 30.

Crown Agents for the Colonies.

Some of the business in England for the smaller Colonies is managed by the Crown Agents for the Colonies in London. The Crown Agents consist of two or more officials appointed by the Secretary of State for the Colonies, and these agents are aided by a sufficient staff of assistants and professional advisers. The agents and their assistants are paid by salaries, and make no other pecuniary profit from their office; and as the total expenses of the establishment are provided by contributions from about thirty Colonial Possessions, in proportions according to the services they require, the cost to each is very little. The Crown Agents negotiate Colonial loans, arrange with English contractors for the construction of railways, purchase material for railways, harbours, bridges, or waterworks, and generally perform the duties necessary for Colonies who depend on Great Britain for their supplies.

Colonial Agents-General.

Most of the larger representative or self-governed Colonies have appointed agencies of their own in London, consisting generally of an Agent-General and staff, who, besides attending to the business just described, promote emigration and attend to the political interests of their respective Colonies; but occasionally even in some of these cases the agents associate themselves with the Crown Agents for important or delicate matters, such as the negotiation of loans or the administration of railways. In these Colonies there is an increasing public opinion in favour of local contractors, and in some of favouring local manufacturers by protective tariffs.

But whether managed by the Crown Agents, or separately by their own special agencies, the business of the Colonies in England is administered independently of the Home Government, which (except that it has promoted the establishment of the Crown Agents) interferes neither with their loans nor with the public works or purchases to which the produce of the loans is applied.

See INDIAN GUARANTEES, *page* 34.

Public works of India.

In India the principal railways have been constructed by means of private capital, but with Government guarantees. The Government of India thought it, however, expedient to abandon this policy, and has since constructed railways and other works out of current revenue or with money raised by public loan. The Local Governments and Administrations have a limited power of undertaking railways and other public works by means of capital borrowed on the security of local revenues; but the principal works are undertaken only when recommended by the Governor-General in India in Council, and sanctioned by the Secretary of State for India in London.

In the opinion of those best able to judge, there is great need and ample opportunity for more railways in India, if the Government would encourage private enterprise by facilities and by moderate guarantees. The direction in which State railways are likely to be extended will be determined as much by strategical as commercial requirements, but the latter are sufficient alone to justify extension.

Crown Colonies.

In the smaller Dependencies of Great Britain, which are administered as Crown Colonies, where there is no Legislature, all public works have to be sanctioned by the Secretary of State for the Colonies in London. If sanctioned, the expenditure for minor works, such as the maintenance of roads, is made direct from the local revenues; but all large contracts and all purchases in England are arranged by the Crown Agents for the Colonies.

Fortified stations.

The works connected with the defences of fortified stations, such as Gibraltar, Malta, and Bermuda, are managed by the Engineering Departments of the War Office and Admiralty in London, although the civil business even of these Dependencies is conducted by the Crown Agents for the Colonies.

Room for private enterprise.

While, however, the Colonial and Indian railways, harbours, and other important works, which are beyond the means of local revenues, are thus constructed by means of borrowed capital, or in the case of smaller Dependencies and fortified stations by funds voted by the Imperial Legislature, and while the carrying out of the works is paid for in money as regularly as in England, there is ample room for enterprise in many smaller affairs of the kind described in succeeding chapters, and which, besides the aid of the contractor, require that of speculative capitalists.

Foreign works. *See* CONCESSIONS, *page* 18.

English aid invited.

But in other foreign countries, and especially in those semi-civilised or newly-settled, the Government has very different duties to perform. The construction of roads, railways, harbours, and other works may be all important to the progress and prosperity of the country, and yet there may be neither skill nor capital available. Outside aid has therefore to be invited, and this can be done successfully only by offering facilities, granting concessions, and, in fact, permitting and assisting the foreign capitalist to perform the works and to reap the profits arising from them, leaving for the people of the country the general or indirect benefits which will result. Instead, therefore, of having, as in Great Britain, to satisfy rigid conditions, to conform to fixed rules, and to pay largely for land and compensation, the English capitalist has offered to him abroad, facilities and inducements which may appear liberal, but which necessitate on his part the close inspection, the rigid inquiry, and the guarantees which in England he would be obliged to assent to rather than to demand.

Land facilities.

See LAND, *page* 26.

There are not in new or sparsely-populated countries the numerous and diversified vested interests which stand in the way of undertakings in Great Britain; nor are the vested interests which have grown up so strictly regarded; and especially is this the case with the most powerful of interests, that of the owners and occupiers of land. Abundance of land, and facilities for acquiring it, go far to compensate for the lack of capital and skill; and, indeed, many of the most successful engineering enterprises carried out in foreign countries would have been impossible had it not been for the great facilities granted with regard to land.

Cost of municipal works.

The money necessary for town-drainage, street-cleaning, and similar municipal works, is generally raised by local taxation; and

Local taxation.

Octroi duties.

Costly and inconvenient.

London coal duties.

only occasionally—as sometimes in the case of capital cities—do national funds contribute. In some foreign cities the expenses are defrayed by indirect municipal taxes, levied in the shape of *octroi* duty on goods or provisions entering the city, and the inhabitants in most such cases would resent the imposition of the more economical, though apparently more oppressive, direct taxation by rates according to rental. *Octroi* duties require the employment of numerous officials; involve smuggling, with its attendant evils; and cause an enhancement of price to the retail purchaser, equivalent not merely to the tax but also to the profit on the tax which each trader through whose hands the commodities pass puts upon his outlay. To these immediate evils are added delays and other restraints of trade which interference always involves, an *octroi* duty often being in effect a transit tax on goods merely passing through the town; for though systems of drawbacks or refunding are generally established, the regulations are vexatious enough to turn the scale against a town so hampered, in the competition of traders to make the market an entrepôt or centre of commerce. In England, *octroi* taxation is almost unknown, except in the case of port or harbour dues, which are most frequently levied on coal or corn, and are in some English towns applied to municipal purposes. In this way the wine and coal duties of London were perpetuated, and 13*d.* per ton levied on all coal entering the metropolitan district (an area of more than 500 square miles) was applied to the main drainage and the freeing of toll bridges. The tax ceased in 1889.

CHAPTER II.

CONCESSIONS FOR ENGINEERING ENTERPRISES IN FOREIGN COUNTRIES.

MONOPOLIES. SUBSIDIES. GUARANTEES.

Concessions defined.

THE word "Concession," which has been placed at the head of this chapter, is a general term, which is well understood now-a-days to express the grant or permission from a State or other authority which alone can authorise the execution of any public work. Such enterprises are either those of public utility, such as Railways, Harbours, Bridges; or those of local utility, such as Water, Gas, or Drainage works.

Promoters.

In foreign cities or countries, the demand for works of these kinds may come directly from the Government or the inhabitants, or may be suggested in the first instance by those who hope to make a profit if they can only arouse a desire for the works in question. Those who procure the concession and thus initiate or lead the way in such enterprises are generally known as promoters.

Works constructed by public money.

In many foreign countries there are, as in Great Britain, ample means for paying for works of utility. A Government or Municipality may provide the money out of public funds, or may raise the money by taxes, imposts, or rates levied for the purpose. A few private capitalists may unite, or public contributions, small and great, if sufficient in the aggregate, may, through the ordinary machinery of a joint-stock company, be rendered available. In such cases as these, if outside aid be sought, it is only for engineering skill to design, or for contractors with experience and means to carry out, the works, or for both these purposes. But it often happens that the necessary funds are not forthcoming, and the aid of the British capitalist, as well as that of the engineer or contractor, has to be obtained.

British aid required.

Deferred payments.

Perhaps the Government, or Municipality, may be able to pay, but only in obligations or bonds instead of in money; or although able ultimately to pay in money, cannot do so till the work in

Capitalist contractors. *See pages* 40, 238

question is completed. In either case somebody must provide money to pay for the works during progress, and here the functions of the capitalist, or the capitalist-contractor, commence. There is a great variety of circumstances and combinations in these matters; and in this and the following chapters some suggestions are made with regard to the financial, local, and technical conditions which are essential to success.

Ample information necessary.

In asking consideration for any new scheme, the first duty of the promoter is to furnish ample information; and, simple as such a condition may appear, it is one seldom thoroughly appreciated. The following statement of what the preliminary information should include, applies generally to most engineering enterprises, and it will be seen throughout that five interests are in view, those of the public, the capitalist, the engineer, the contractor, and the promoter. It is impossible to distinguish exactly between these interests, as the functions of each class are often combined, or overlap those of the others. According to the manner in which an enterprise is presented for consideration, and the kind of aid which is sought, will the different suggestions in the following pages apply. The information which will be required may be classified as follows:—

Information classified.

1. The Nature of the Undertaking.
2. The Need for the New Undertaking.
3. The Terms and Validity of the Concession. *See page* 21.
4. The Estimated Cost of the Undertaking. *See page* 21.
5. The Nature and Amount of the Payment or Profit. *See page* 22.
6. Under what Control and Jurisdiction the Works are to be executed and maintained. *See page* 24.
7. The Price or Consideration to be paid for the Concession. *See page* 25.

Nature of the undertaking.

1. *The Nature of the Undertaking.*—The work having been specified as Railway, Harbour, or otherwise, the extent and objects of the work should be stated. The detailed technical and local information required is described in succeeding chapters, under the respective headings of the various undertakings.

2. *The Need for the New Undertaking.*—It is obvious that enterprise directed towards the supply of an indisputable want, is more likely to succeed than where—other conditions being equal—the need is problematical, or is not obvious. If the want in the locality is not sufficiently notorious, and if, as a justification for the new enterprise, the success of similar schemes elsewhere is adduced, evidence

Need for new undertakings

Insufficient scope.

Competing railways.

Over-supply reduces prices.

See COPPER, *p.* 369.

Scarcity raises prices.

will be required to show that the circumstances of the different localities are sufficiently alike to warrant the representations of the promoter. But even if there is the assurance of good management under conditions seemingly as favourable as before, it is necessary to show that there is sufficient scope for the new enterprise. Of the various points of view from which such cases will have to be regarded, two examples may be given. A railway may be projected in a district where an existing railway already runs, and although the new line may pass through different towns, it may interfere with or rival the older undertaking. The commerce, existing or probable, of the locality may not within a reasonable time be able to provide sufficient traffic for the two, and the rates for even this diminished traffic may, by the new competition, be reduced. Or, to take another example, capital may be sought to work a quarry of marble of a very high quality. It may be indubitably shown that similar marble sells for forty shillings per cubic foot, and it may be proved with equal clearness that every week five hundred cubic feet of marble can be got from the new quarry at a cost of twenty shillings per foot. The calculation of profit appears easy. But there is probably only a limited demand for so high a quality of marble; new customers for five hundred feet per week may not easily be found: and the new quarry will only be able to share in the trade of the existing quarries. But more than this, the buyers of marble, hearing that capital is being sunk in a new quarry, will postpone their purchases in the hope that the coming competition will reduce prices; an immediate reduction in price will probably be the result; and the proprietors of the new quarry may find, when they are ready to sell, that the mere anticipation of their sales has caused the market price of this kind of marble to fall; and that they can only sell one hundred feet per week, at a price of thirty shillings per foot. Of course an example of this kind applies with less force to an article in common demand, such as coal, iron, or copper; but the same principle applies in most cases in some degree. The value of copper fell from £80 to £40 per ton in a short time from this cause, notwithstanding a large increase in the consumption of copper. And it must be borne in mind that an increase in the supply will generally have a more than proportionate effect on prices. Thus if in the corn market there is an increase of 5 per cent. in the supply, prices will probably fall more than 5 per cent., because of the competition of all sellers to dispose of their stock. A scarcity tells as strongly in the opposite way, for if the supply be reduced 5 per cent., prices may rise 10 per cent., in the struggle of many buyers wishing to buy before the prices rise higher, and the comparative indifference of sellers to part quickly with their goods in a rising market. Weight must, however, be given to the fact that a supply sometimes creates a demand; and this especially is the case where the price is reduced or where a new enterprise is commenced in a thriving or growing community. A railway causes traffic that never existed before; a convenient harbour brings ships; electric lighting awakens a desire for the improved light; a new market-hall tempts customers.

Supply creates demand.

3. *The Terms and Validity of the Concession.*—The kind of concession, or the terms on which the work is to be undertaken, must be fully set forth, and especially with reference to the conditions enumerated on pages 23 to 33. It must be shown that the official or other bodies who have granted the concession have acted within their powers; and the confirmation should be produced of any Sovereign, President, or Assembly whose consent is necessary. To still further give satisfaction on this point, it must be shown that the concession does not clash with any granted previously, or with any existing privileges. Written concessions, documentary evidence of all kinds, and signatures, should admit of verification, and—in the case of countries not under British jurisdiction—should be so verified by notarial and consular declarations.

Terms of concession.

Validity.

4. *The Estimated Cost of the Undertaking.*—In the case of railways, harbours, and other large works, preliminary surveys and estimates by competent engineers are necessary, and promoters should at an early stage obtain by these means at least some approximate idea of cost. They have therefore to decide upon the amount of money they will spend in these preliminary investigations. Sometimes, where similar works have been executed elsewhere under somewhat similar conditions, the experience so gained may be sufficient for preliminary purposes; but where such evidence stands alone, it is always received with hesitation. In cases, however, where structures or machinery form a large proportion of the scheme, where the local circumstances do not therefore form a very important element in the cost, sufficiently accurate estimates may be made in England, if the essential and easily-obtainable particulars are furnished. The nature of the information required for different kinds of works is described in each case as it occurs in the following chapters. If, however, to obtain sufficient information, preliminary

Estimated cost of works.

Preliminary expenses.

surveys are necessary, and the promoters having only furnished meagre information, invoke the aid of the capitalists to make these surveys, they will probably have to give the option of taking up the concession on certain terms, or otherwise bind themselves for a certain period to whoever so aids them.

By whom defrayed.

Preliminary expenses fall properly on the promoters, and those promoters who show a disposition to share in the risks of a new enterprise are always listened to with more attention than are those who ask that all may be done for them. Such willingness is naturally taken as proof of confidence in the soundness of a scheme. So also the co-operation of local capitalists has weight. However poor a country may be, it seldom happens that there are not some who have means for profitable undertakings; and as people residing on the spot have special facilities for estimating the probabilities of success, and would—unlike the foreign capitalist—share in the indirect public advantages expected from the scheme, the absence of such home aid suggests doubts as to the genuineness of the enterprise. There are, of course, exceptions to this rule in those cases where the local capitalists, never having seen similar undertakings before, or being ignorant of the benefits that will result, hesitate to join in an expenditure of which the returns seem to be problematical. So, also, there are cases in which it is expedient to keep the capital within a limited circle.

Assistance of local capitalists.

Spare capital advantageous.

In estimating the cost of any new undertaking, sufficient margin must be left, not only for contingencies during construction, but for working capital and expense of management after completion, until sufficient revenue is forthcoming. Even if the spare capital be not called up, it is most important that it be available when required, as without it, money has often to be raised on onerous conditions, which absorb the profits of the enterprise. The interest on capital during construction has also to be considered.

Payment and profit.

5. *The Nature and Amount of the Payment or Profit.*—This is obviously one of the most important matters in connection with a new enterprise, and as it is one which more than any other determines the adoption or rejection by capitalists of a project presented for their consideration, it is useless to present it unless full information be furnished on which the profits may be estimated.

Where simple and secure money payments are offered in return for material to be supplied, for services to be rendered, or works to be executed, ordinary and well-known conditions of business will apply; and occasional mention is made of these in succeeding chapters. The regular money payments made to contractors in England and her Colonies have been already referred to; the conditions of payment usual in purchasing material for shipment to a foreign country will be also described further on. But in many of the foreign enterprises brought to England for consideration and adoption, the kind of payment or profit offered in return for the aid which is sought is of an entirely different nature to the foregoing, mainly because such profit is deferred or speculative. The mere fact of having to depend on payments in a foreign country not under English jurisdiction, is in itself a cause of hesitation to many capitalists and contractors; but the facilities which now exist for international transactions render this difficulty a small one where legal remedies are as certain and as capable of enforcement as in England. A serious difficulty, and one which often forms a bar to British enterprise abroad, is the want of sufficient legal security, or the hampering of the concession or contract by conditions, the risks of which are not easily measured.

See pages 14 *and* 15.

See PURCHASE FOR EXPORT. *Chap. XVII.*

Deferred payments.

Security wanting. *See page* 54

Capitalists generally value the payment or profit offered to them in proportion as it appears marketable or transferable to others. In some cases—and these are the really speculative ones—capitalists employ their own money temporarily in the hope of transferring their property in the undertaking at an enhanced price when they have developed it. In other cases they assure themselves of this transfer before they commit themselves to the enterprise. The separate functions of the contractor and the capitalist are further defined in another chapter; but in any case, if the work is to be paid for as it proceeds, the periods, conditions, and amounts of the payments will have to be very clearly defined; and when this stage in the negotiations is reached, the promoters must be prepared to give satisfactory information as to the ability and intentions of those who have to pay. If the profit of the capitalists is to consist, all or in part, of revenue to be derived from the work itself, very complete information on this point will be required; and as the evidence adduced will be subjected to rigid examination, the promoters must be prepared to show the data on which the calculations of expected earnings have been based, and to afford opportunities for verification. In cases where payments for a new undertaking are to be made without reference to future revenue, it is still desirable to furnish such information, so that if satisfactory, the capitalists or contractors may have

Power of transfer needed.

See page 41.

Verification of earnings.

the more confidence in the soundness of the undertaking, and in the ability of those interested to pay for the construction. It is never desirable to be connected with what may possibly become an unprofitable or unfortunate speculation, even if free from a share in the direct loss.

Control of works.

Engineer's certificates.

Maintenance and management.

6. *Under what Control and Jurisdiction* the works are to be executed and maintained. It is necessary that the contractors or capitalists should have confidence in the ability and fairness of the engineer or other person under whose direction the works are to be carried on. In the case of works executed in foreign countries, the authorities who grant the concession frequently require that their own engineers shall control the execution, and, as a condition of payment, certify concerning the progress and completion of the works. It often happens, however, that the works have to be designed as well as carried out by British aid, and in such cases it is natural that the engineer who designed shall superintend the construction, and certify the completion. The justice of such a condition is still more evident when British capitalists provide the means, or an English contractor undertakes the work, and in such cases the capitalist or contractor will generally insist on the appointment of an English engineer, whose certificates shall be received. Not only, however, should the engineer be empowered to certify, but he should be bound to do so when the certificate becomes due; and provision should be made in case he is unwilling or unable to perform this necessary function. If the certificate is given by the engineer directly to those who are to pay, a copy of it should be delivered also to the contractor. As the revenue to be earned by the undertaking will greatly depend upon proper maintenance and management, it is important for the capitalists or contractors—if their payment or profit is to be made out of revenue—to know that the management shall be efficient and trustworthy.

Appeal to law.

Jurisdiction.

As the ultimate appeal in case of dispute is always to the law, capitalists are interested in knowing by what law they will be bound during the execution of the contract. If they have doubts as to the stability, powers, or fairness of the courts which will have jurisdiction, they may probably require security of some kind in Great Britain or in some neutral hands. Questions of this sort, and those concerning arbitration, are matters for consideration in every contract, and need not be further referred to here.

Price of the concession.

7. *The Price or Consideration to be paid for the Concession.*—It

sometimes happens that the capitalists or contractors treat directly with the public or other body which requires the works in question, without introduction by any third party. In such cases it may be that no payment or consideration has to be made beyond the works specified in the concession itself; but in many cases the earlier negotiations are carried on by persons locally interested, or by those who, having heard of a possibly profitable enterprise, arrange conditionally the terms of a concession, and then seek for capitalists to take it off their hands. This is a perfectly legitimate position when fairly taken up, and is often a source of considerable profit. In some cases a promoter demands a specific sum as a consideration for introducing a profitable undertaking. If the profits appear very certain he may obtain payment at once, or may be content with deferred payments spread over a considerable period. The promoter, however, induces confidence by allowing his own profit to be dependent on the success of the enterprise. This may be arranged by postponing his own payments till the completion of the works, or—if the capital be raised by means of a joint-stock company—by taking his payment in shares or debentures, whose value will depend on the earnings of the undertaking. If a promoter is content with an equitable arrangement of this sort, he may at the same time stipulate for an immediate repayment of the actual expenses already incurred. If these are not unreasonable in amount, they may be treated as part of the general expenses of the undertaking, and paid for out of the new capital to be introduced. Whatever these payments may be, they should be explicitly and fully stated in all documents inviting public subscriptions.

Promoters' profits.

Payment to promoter deferred.

The capitalists may naturally stipulate for the assistance of the promoter during the construction of the works, and expect his influence in the negotiations as well during the progress as at the final settlement. This is another reason why some of the payments to the promoter should be postponed, so that it may be his interest as well as his duty to give his aid throughout.

Concessions vary.

A Government, a Province, or a Municipality may grant concessions in various ways:—

Permission granted.

A simple Permission may be granted for the execution of the works, the concessionnaires being left to make their own arrangements for the purchase of land, rates of tolls, and all other necessary matters. If the enterprise promises sufficient profit, this permission may be all that the capitalists will require, and if they have confidence in the laws of the country, and have no fear of anything like confiscation, they will construct the works, trusting either to sell them when completed, or to derive from them a sufficiently remunerative revenue.

Facilities granted.

Facilities or Immunities may be granted.—The Government of a country may do much to assist and encourage works of utility even in those cases where the initiation and carrying out of works are left to private enterprise. Especially is the assistance of a Government needed in a new or unexplored country, to investigate its mineral and other resources, to make surveys and maps, and to record the information thus obtained in a convenient form for reference. Engineering enterprise will follow more quickly if such information be afforded; a basis is created on which roads and bridges can be projected, and the further development of the country is greatly facilitated. Hydrographical charts, river explorations, mineralogical and meteorological reports are equally important, and a Government which thus paves the way for public works, in most cases does more for the real advantage of the country than by spending the same amount of money directly in railways, telegraphs, mines, and other works, which are more likely to be successful when undertaken by private capitalists. But to these earlier services which fall within the legitimate province of a Government, must—if capitalists are to be satisfied—be added the essential safeguards of equitable laws, which ensure safety to person and property.

Government surveys. *See page 74.*

Equitable laws. *See page 54.*

In works covering any considerable extent of ground, the acquisition of the land is one of the first matters to be arranged, and one in which some official authorisation is necessary. Such authorisation is generally required in Great Britain, where railways and other public works are sanctioned by Parliament, which allows the compulsory purchase of land. Even in countries where the new undertaking is so welcome as to induce landowners to give their land gratuitously, it is well to obtain such powers as will overcome, if necessary, the possible opposition of any landowners. In some cases the Government or Municipality will give land or site gratuitously, or at a merely nominal price; the expropriation of the land, and the negotiations necessary for that purpose, being often undertaken by a Government, who guarantee the price and terms on which the land may be acquired even in cases where they do not assist the

See Chap. I.

Land given gratuitously.

See page 75.

enterprise in any other way. A Government can generally obtain the land on easier terms than would be possible by concessionnaires, especially if they be foreigners, although in some cases it is at the expense of private rights. For in many foreign countries the State is not only paramount, but the individual is almost disregarded, and to aid in an undertaking which is declared to be for the public convenience, he is compelled to sell his land at an arbitrary price fixed by public officials. Mining privileges are accorded in many countries on specially easy terms, with facilities for acquiring surface land sufficient for the necessary works.

See MINING, *page* 344.

Immunities granted.

Immunities also may be granted by the exemption from import or other dues of the tools or materials to be used in construction, or by exempting for a term of years the revenue from taxes, or by allowing the use of Government wharfs, railways, or canals gratuitously or at favourably low rates.

Subsidies.

A Subsidy may be granted.—In some cases the undertaking may be of such importance to a country, a province, or a town, that the authorities will offer an inducement to foreign capitalists in the shape of a money payment. Such a subsidy may be made payable when the work is completed; but if the principle of a subsidy be admitted, and if the undertaking be a large one, payments at certain specified periods during progress are generally agreed upon. Sometimes the subsidy may not be in money but in land. A new railway or harbour; irrigation, drainage, or reclamation works may be expected so to improve the adjoining land as to render it valuable. In such cases it is not unusual to share with the capitalists the land thus to be improved. In railways, for instance, alternate blocks of land on either side of the line are often pledged to the capitalists, and become their property as the line is completed. In a new country where land is plentiful, this is frequently an advantageous arrangement for both parties, and one easily adopted, because the land before the railway or other works are executed is generally of little value. It is the judicious selection of such surplus land with the view to future population and ulterior profit, that has rendered so many colonial or foreign railways practicable or possible. Land being capable of subdivision can be sold in large or small lots to suit purchasers; and bonds which represent the land, and prospectively pledge it as the works are completed, are thus available for large or small investors, who do not care to participate directly in the risks of the enterprise.

Grants of Land.

To railway companies.

Land-bonds marketable.

If engagements for subsidies are entered into with stable Governments whose credit is unblemished, they are of very great assistance in the raising of funds for the works; but subsidies are sometimes considered objectionable, as involving too much Government control or official interference.

Subsidies must be clear.

It is of course necessary in regard to all subsidies to see that the written engagements are clear, well defined, and within the powers and capabilities of the subsidising authority.. If bonds which represent engagements are qualified by vague or numerous conditions, it is obvious that they possess little negotiable value for the investor who buys them. Where land is offered as a subsidy, it is especially important to ascertain that those who promise to give it have the right to do so, as cases are not unknown where land pledged by a Government has been afterwards found to be burdened by proprietary or other earlier rights.

Monopolies.

A Monopoly may be granted.—It happens sometimes that the mere giving of permission to execute works may, in effect, be the granting of a monopoly, as there may not be room for two undertakings of the same sort. A monopoly in express terms is of course the more valuable concession, as it is a protection either against rival schemes which may be projected simply to be bought up, or against the more or less legitimate rivalry at a future time when the profits may have so increased as to invite such competing undertakings. A monopoly is generally for a term of years; and if the nature of the undertaking requires it, is defined by a distance, as, for instance, by miles on each side of a railway, or, in the case of a toll-bridge, by distance along the stream above and below the bridge. In some countries, where it is considered desirable to encourage the enterprise of capitalists, a monopoly for a term of years may be claimed as a right by whoever inaugurates a new industry.

For terms of years.

Objections to monopolies.

Exceptions.

See BRIDGES, *p.* 134. WATER, *p.* 196; GAS, *p.* 239; ELECTRICITY, *p.* 270; TRAMWAYS, *p.* 291; MARKETS, *p.* 331.

As a general rule it may be affirmed that the granting of monopolies is not an economical method of executing works of utility, and is not in the true interests of the public. There are exceptions to this rule, as in the water supply of a town, or in some instances of a gas, electric-lighting, or tramway undertaking. The monopoly is then qualified by conditions framed in the interests of the community. So also in a new or undeveloped country, where the undertaking is one of which the profits are speculative, the utility of the works executed may be such as to warrant some encouragement or security to the capitalists who are willing to speculate. In England monopolies are seldom granted, and railway shareholders, among others, complain that rival lines are permitted to invade territory already occupied, and to diminish profits. In France and many other countries, shareholders are in effect, even if not by direct legislation, protected from competition; but it is probable that the English system has, by the stimulus given to trade, proved more advantageous to the nation at large than the artificial protection given in France.

Enforced monopolies.

A Monopoly may be made absolute by Enforcement.—When the new undertaking is completed, those works previously existing which it is to replace, may be stopped. For instance, with a new harbour, the landing of all goods at it may be enforced; or all goods landed within a certain distance of it subjected to toll. With a new bridge, old roads may be directed to it; with new waterworks, old conduits may be removed, or all houses compelled to use the new supply; if new markets are built, they may be made to cover the site of the old ones, or selling in the neighbouring streets may be prohibited; with new abattoirs, their use may be rendered obligatory.

See BRIDGES, *p.* 134.

MARKETS, *p.* 331.

Guaranteed revenue.

A certain Revenue may be Guaranteed.—A Government or Municipality may engage to use the new undertaking, and to pay tolls up to a certain agreed minimum. This may be done in the case of a railway, waterworks, bridge, or any undertaking which depends upon tolls or dues for profit. Sometimes the guarantee may proceed from landowners, merchants, or existing companies, who are interested in encouraging the new undertaking. In these cases where the guarantee proceeds from other than State or Municipal authorities, great care is necessary to make precise and safe engagements. It often happens that a minimum revenue thus secured is of itself sufficient to pay a moderate interest on the outlay incurred, and with this safe minimum, capitalists will be the more willing to incur some risk with respect to the possible surplus profit.

Guaranteed interest.

A certain Interest may be Guaranteed on a specified amount of expenditure. In countries too poor to raise the capital necessary for public works, there may be no insurmountable difficulty in paying interest on capital provided by others. If a Government, Municipality, or other public body, is willing to guarantee interest, it is to be presumed that the undertaking is much required, and is expected

For works of public utility.

to be of great value to the community when completed. Perhaps this value may be shown directly in the shape of revenue sufficient to pay the interest; in other cases the undertaking may be remunerative only indirectly, by removing obstacles, promoting commerce, or otherwise. Such advantages may render a community, or those who are to be benefited, able and willing to pay tolls or taxes sufficient for the interest.

Various kinds of guarantees.

A guarantee may be granted in a variety of ways. Sometimes the merchants, landowners, or others who are interested in promoting the new work, will themselves provide a portion of the necessary capital; the Government or Municipality will guarantee interest on a second portion; and the capitalists who provide this second portion with interest thus secured, may be willing to provide the third and unguaranteed portion also, if upon it the revenue earned by the whole is pledged to pay them a preferential interest; or the guarantee may be only to the extent of a minimum interest, which, though not in itself sufficient to tempt investors, may so remove the risk of absolute loss as to render them willing to venture. Thus there may be an enterprise which in the mind of the investor is—if unguaranteed—of a character so speculative as to require a probable return of 10 per cent. to induce him to join in it. But if a minimum of 4 per cent. be secured to him, he may be willing to invest, even if he sees a probability of but 8 per cent. in all. A concession which guarantees interest is most popular with investors, and if the credit of the guarantors be sound, is more easily negotiated than a concession promising much larger but unguaranteed profits, or even than one granting a subsidy. When capital is raised in this way by a Government, the transaction resembles in some measure a public loan, and the interest it would be found necessary to offer for a loan may serve as an approximate guide to what is required in a guarantee.

A minimum interest secured.

Loans and guarantees compared.

But there are differences between a loan and a guarantee, which may be noted. A Government loan generally pledges the national credit absolutely and unconditionally, and the lender need have little concern in any public works which may be the occasion of the loan, unless, indeed, they are pledged as collateral security. But, on the other hand, the mere guarantee by a Government of interest on the capital of some enterprise in private hands—say on bonds issued by a company—will not always secure the acceptance of so low a rate of interest as would suffice on the national loan pure and simple. The guaranteed bonds are generally hampered with

Guarantees qualified by conditions.

conditions; they do not appeal to so wide a class of investors; they may not in the aggregate be of sufficient amount to be spread over many money markets; and, as less known, may be less negotiable, and therefore less valuable than ordinary Government stock. Thus if a Government be of such sufficient credit as to borrow at 4 per cent., it is not improbable, if they offer a guaranteed interest on the bonds issued by a private company, that 5 per cent. may be needed in order to make such bonds as saleable as the stock of a Government loan. For these reasons, Governments who can borrow at a moderate rate of interest will often find it to their advantage to do so, rather than to pledge their credit indirectly in guarantees. It is in this way that so many of the British Colonies, borrowing in Great Britain at low rates, have been able to construct State railways at a cost which only prompt money payments to the contractors renders possible. Comparing, however, one kind of loan with another, that in which money is raised for the specific purpose of public works of a remunerative nature will, if honestly managed, be more likely to be received with confidence than a loan raised to defray current expenditure, which may be applied to military or other unremunerative purposes. But even in the former case it is necessary sometimes that the investors should be protected against misappropriation of the funds, and they may require to be satisfied, not only that the entire works can be completed for the sum estimated, but also that the capital raised will only leave their custody, or that of trustees in whom they have confidence, on the certificate of a competent person that a corresponding portion of the work is accomplished.

Rates of interest.

See page 14.

Different Government loans compared.

These remarks obviously apply only where the guaranteed interest is alone under consideration. If besides the guaranteed minimum, a higher interest is expected from the enterprise itself, then of course a speculative value is offered to the investors apart altogether from that afforded by the guarantee. Moreover, capitalists or contractors who engage to receive guaranteed bonds in payment for works, incur certain expenses of discount and brokerage, and their price for the service rendered is enhanced accordingly.

Expenses of brokerage.

Although unconditional national guarantees are generally most trustworthy, the reverse is sometimes the case. National guarantees may be injuriously affected by political influences or changes of Government; and it has thus sometimes happened that in countries where national guarantees and obligations have proved fallacious, a municipality or province has maintained a character for fair dealing.

Provincial and Municipal guarantees.

But although in certain cases the real comparative value of different guarantees may be thus stated, national obligations or bonds are generally more easily negotiable because they are better known, and because Governments are considered more amenable to diplomatic influence and public opinion.

Private guarantees.

Private individuals, corporations, companies, or the owners of existing properties, which are to be benefited by the new undertaking, sometimes give guarantees. For instance, the owners of a railway, or group of railways, may anticipate benefit from the construction of another railway, or of an important bridge, or of a harbour, and without themselves having the funds available for the purpose, may be so satisfied of its importance as to pledge their own revenue in addition to that anticipated from the works contemplated, so as to ensure an interest equal to that paid on their own capital or even a preferential interest. The revenue thus pledged may possibly have been so constant or progressive in the past as to be received almost as an absolute guarantee; but as a rule this latter is preferred, and investors will scan with great caution, not only the exact wording of a merely preferential guarantee, but the legal security which is offered for its fulfilment.

See BRIDGES, *p.* 135; WATERWORKS, *p.* 196.

Preferential guarantees.

Negotiable bonds.

Whatever be the nature of the guarantee, it should be recorded as explicitly as possible. It much facilitates the raising of capital if a guaranteed interest or subsidy be expressed in well-defined bonds which can be made negotiable. The exact manner of doing this is, of course, a matter for arrangement in each particular case. A Government or Municipality, or any corporate body, which expresses its engagements in bonds, may word them either so that their liability comes into force only when the entire works are completed, or, as has been before stated, so that they take effect from time to time, *pro rata*, as the works reach different stages. When the credit of the guarantors is good, there will be found capitalists who can afford to wait for a considerable time for a return; and there are also to be found contractors of sufficient experience and reputation to induce capitalists to embark their money in enterprises whose success depends entirely on the fulfilment by the contractors of their engagements. This is generally facilitated when the contractors themselves share in the enterprise as capitalists, and thus afford the best proof of their confidence in the enterprise and in their own capabilities. But the willingness of capitalists or contractors to wait for a return depends entirely on the margin of estimated profit.

Deferred profits.

There is the further question, often important to the investor, of the loss of interest on his capital during the construction of the works, and till they become remunerative. The ultimate profit may be deemed sufficient only if it is enough to repay the income so lost as well as current interest; and it is sometimes sought to anticipate this return by requiring from the contractor the payment of interest during construction, the contractor adding to his price accordingly. This system, having been abused in some instances, was disallowed in English schemes seeking Parliamentary powers; but although it should be obvious to the investors that the interest so paid them is not really earned but is merely paid out of their own capital, the system has its attractions, and Parliament has sanctioned it in cases where it was found to facilitate the raising of capital for important works.

Interest on capital during construction.

Interest paid by contractor.

Great care is necessary in expressing the exact terms of a guarantee, so as really to include all that it is supposed to cover. As an example, a trustworthy Government may give an absolute guarantee of a certain rate of interest on a specified amount of capital which is required for a new railway, and the transaction appears a safe one. But possibly there is the reasonable stipulation that the concessionnaires shall not only make the line but work it, and if the traffic prove so small as not to pay working expenses, some of the guaranteed interest may have to be expended in making up the deficiency. The Government may decline to pay this deficiency. Thus, for a line estimated to cost a million sterling, a Government may guarantee, and, if needed, pay 7 per cent. per annum on bonds to this amount, *i. e.* £70,000, all the net revenue up to this point going to reduce the amount, and all beyond it being shared by the Government and the railway company. The Government pays the interest as agreed, and their obligation ends. But there may not only be no net revenue, but the receipts may not pay working expenses. A sparsely-peopled country, a small traffic, or rates of freight which are too low, but which may have been made a condition of the concession, may cause this deficiency. The above is an additional reason why concessionnaires should investigate the probabilities of profit, even if there be a guarantee.

Precision in terms necessary.

Fallacious guarantees.

See page 70.

The principle of assisting or encouraging works of utility by guaranteeing a revenue or interest on capital, is one which is often carried too far. Indeed, in any but new or undeveloped countries it may be laid down as a rule generally acknowledged that it is not in the true interests of the community to give guarantees at all, and in the

Guarantees inexpedient.

Government works.

many cases where Government guarantees have been necessary to induce capitalists to construct public works, such a method should be abandoned as soon as possible. If in any country or in regard to any class of works, the system has been apparently established, capitalists will continue to depend on it. But when once the earlier enterprises of a kind so encouraged have been sufficiently developed to prove whether they are, or are likely to be, remunerative, one of two conclusions is generally obtained: either that the works will be in themselves remunerative, or that they will not. In the former case, capitalists will be found to venture, and in the latter the Government of the country should carry out the undertakings they may deem necessary directly with public money.

India an example.

See page 15; *also* IRRIGATION, *page* 181.

Guaranteed railways in India.

Government interference.

India affords examples of both kinds in her irrigation and railway works. The application of private capital to irrigation, whether with or without guarantees, has in very many cases proved a failure, but as in some districts profitable results appear probable, it can hardly be doubted that private capital would be directed towards the most promising localities, even if guarantees, so long considered necessary, were refused; while in cases too speculative for the private capitalist, but considered expedient by the Government, the works ought to be carried out directly with public money. In the case of railways, though a revenue more than enough in itself to pay interest on capital has on some of the lines been obtained, and nearly enough on others, the prospects of dividend do not keep pace with the extensions deemed necessary by the Government; and the good credit which made guarantees so valuable has been applied directly to the borrowing of money for State railways. In India, however, the Government has not gone far enough in the extension of railways, and has refrained also from giving to private capitalists the facilities and moderate guarantees which alone are necessary to obtain their aid. A Government guarantee generally involves Government interference which it may be worth some inconvenience to avoid. The guaranteed Indian railways though nominally managed by Boards of Directors are under control. Whether the money for public works be obtained by loans or by guarantees, the construction of the works is almost always better left to private contractors.

Even where there are fair prospects of success, Governments or communities will in vain invite capitalists to provide money for works of utility, unless they can assure to the investors absolute security by law, and reasonable facilities for the carrying out of their projects.

Obligations in return.

Rent demanded.

Rent capitalised.

Payment in kind.

Endowments.

Having now enumerated some of the different kinds of concessions, it may be laid down as a general principle with regard to them all, that the greater the privileges granted, the more onerous will be the payments, services, or conditions demanded in return. In granting permission to execute works, accompanied by facilities, immunities, monopoly, subsidy, or guarantee, the authority which concedes does so in consideration of work to be done, services to be rendered, or payments to be made; and, in the interests of the public, makes as good a bargain as possible. Sometimes the authorities who grant valuable privileges may require a fixed annual rent. In other cases—especially where the conceding party is greatly in want of money—the annual rent or expected share of profit is capitalised, and the sum thus arrived at is demanded in advance from the concessionnaires. In others, a Government grants privileges for which it requires a payment in kind, in other words, it stipulates for a part of the results which the enterprise in question is to furnish. Thus, in the case of a railway, the right of free passage for troops may be demanded; with a telegraph line, the reservation of a wire or of priority for Government messages; with a new harbour, the right of Government vessels to share in the use without contributing to the tolls. Another system occasionally adopted is to demand in payment for a concession or monopoly, money for the establishment or maintenance of charitable institutions. An endowment is in this way frequently obtained for hospitals, orphanages, and schools which the Government would not venture or choose to maintain directly out of the public funds.

Quality of works.

See CONTRACT, *p.* 411.

Results specified.

Maintenance of service.

With regard to the construction of works, a standard of quality may be set up, to which the concessionnaries must conform. This standard is generally in the nature of a specification which prescribes the extent and solidity of the works, the quality of the materials, a time for completion, and the results that are to be attained. Sometimes the result only is described, and the concessionnaires are left free to construct the works as they please. When the concession is in the nature of a contract for works for which the contractor is to be paid on completion, or after a limited term of maintenance, the transaction is at an end when this is accomplished. But when anything like a monopoly is granted, and the concessionnaires are to obtain a revenue by tolls or dues from the work itself, it is a reasonable condition that the service shall be efficiently maintained. Thus, in gas or water works, it is stipulated that gas

See GAS, *p.* 237; WATERWORKS, *p.* 193.

See MINING, *page* 344.

or water sufficient in quantity and quality shall be provided at all times during the term of the concession; in a railway or tramway concession, that a sufficient service shall be maintained. The service required is generally defined both in regard to quality and quantity, and it is usual to make the latter depend upon the varying wants of the community, so that if the population increase, or traffic grow larger, the service shall be accordingly extended. In the case of mining privileges, the rights of the concessionnaire generally lapse if the mines cease working.

Levying of tolls.

Excessive rates not allowed.

Equitable terms.

See pages 53 *&* 455.

Mutual profit.

Where dues or tolls are to be levied, their maximum scale or rate is generally set forth in the concession, and great care is necessary on the part of the concessionnaires to see that the scale of charges permitted is sufficient to be remunerative. In some cases the concessionnaires are left free to charge what they think proper, it being considered that excessive rates will be at once checked by the diminished demand and reduced profits which will follow. In cases where the concessionnaires are providing something quite new, such as electric light or a railway, the use of which is optional, and towards which the municipal or other authorities have not contributed, this latitude may be conceded, but where a monopoly of supplying some indispensable want, such as water, has been granted, and if, moreover, this has resulted in the stopping of previous sources of supply, the case is different. But it is generally as much the interest of the concessionnaires as of the public, that rates shall be defined, and in many new undertakings, rates can be agreed upon which will offer accommodation or service to the public on much more favourable terms than those which have been charged for the services which are being replaced; and at the same time afford a fair margin of profit to the concessionnaires. As measures and values are differently stated in different countries, and as in some the currency is liable to fluctuation, it is necessary that these matters should be clearly defined. Indeed, the various considerations which determine the soundness of a new undertaking may be summed up in this, that it shall be profitable to both sides.

A concessionnaire or contractor who has undertaken to perform certain works, stands, so long as the engagement lasts, in the way of any one else undertaking them, and a failure—whether from unwillingness or inability—to complete, generally involves a loss of time before the enterprise can be again started. Moreover, damage or inconvenience may arise from partly finished works. He is, therefore, generally required to give some guarantee for the due fulfilment of his engagements. Sureties or bondsmen are sometimes required, who bind themselves to forfeit the amount of damage suffered up to the amount of their bond if the contractor fails to proceed. The guarantee is in foreign countries more often imposed in the shape of "caution money," which the concessionnaire has to deposit as evidence of his intention, and pledge of his ability, to carry out his engagements. If he fail to commence within a stipulated time, the caution money is forfeited, and is supposed, in some measure, to compensate those who retain it for the trouble, risk, and delay involved in making a bargain with a second contractor. In the case of a monopoly or a concession, the exaction of caution money bars the way to those who—either from insufficient means or want of experience—are incompetent to carry out the work. A similar precaution is included by the English Legislature in Private Bills for railways. A promoter often negotiates the terms of a concession in the hope of transferring it to capitalists with the necessary means, and, in the desire to have the disposal of the concession firmly in his own hands, will sometimes go the length of depositing the caution money. Should any question arise as to the value of the concession, his position will then be one of considerable risk. Or if the works must be commenced by a certain date, he may find it impossible to meet with capitalists to take it off his hands; in either of which cases, instead of obtaining a profit by the transfer of the concession, he may, in order to save the forfeiture of the entire deposit, have to pay a substitute to take the concession from him.

Sureties.

Caution money.

See page 4.

Risk of forfeiture.

Whoever grants the concession generally insists upon holding the caution money, but if the concessionnaire doubts the stability or fairness of the holder, it will be prudent to require that the deposit be in neutral hands. In the case of a Government, the deposit is often made in Government Stock; but, whatever the security, the concessionnaire is generally allowed to draw the dividend or interest on the amount during the period it is held. Sometimes it is stipulated that the caution money shall remain till the undertaking is completed, and that it shall furnish interest on the capital during construction. In other cases the caution money is retained only till the works are so advanced as to have sufficiently committed the concessionnaire to proceed. When once a concessionnaire or contractor has incurred considerable preliminary expense—as, for instance, by providing

Caution money, how held.

See page 453.

plant and purchasing material—the due completion of the work is generally sufficiently insured by the retention of part of the contract price. To hold back the caution money, as well as to retain this part of the price, is a heavy tax on the contractor, and is in many cases not in the true interests of the employer, because if more be thus withheld than is necessary, the competition is limited to the large capitalists who can afford to wait for repayment, and who generally recoup themselves by high prices. Of course when the proportion of the contract price which is retained is made small because the caution money also still remains as a security, then, whatever it may be designated, this caution money is really merged in the retention money, and the two must be considered together and weighed as one total. Fines or penalties for non-completion within a stipulated time are often specified in a concession, and under certain circumstances the concession becomes liable to forfeiture.

Retention.

See PURCHASE, *page* 453.

Fines and penalties.

It is often stipulated in a concession that profits beyond a certain amount shall be shared by the public, either directly, by the concessionnaires paying over all or part of the revenue after a certain point is reached, or by their reducing the rates or tolls charged. This is especially the case where a revenue or rate of interest has been absolutely guaranteed by the conceding parties, who by such a stipulation that the profits shall be shared, may hope to get back again, when the undertaking is developed, what they paid in its earlier stages. The railways in India may be cited as an example; the Indian Government, which in the earlier railways guaranteed 5 per cent. on the capital sunk, divides equally with the shareholders the excess, which is in some cases considerable, beyond 5 per cent. A lower rate of guarantee would now suffice.

Profits shared by guarantors.

In other cases the right of pre-emption is made a condition in the granting of a concession. The conceding authorities reserve the right (to be exercised or not as they elect) of buying up the undertaking at a certain time, and this may be done in various ways. Sometimes a specific price is named; sometimes it is the amount of share capital at par or with a bonus; sometimes at the average price of the shares during the preceding three years; in other cases the price is to be so many years' purchase of the average revenue for a specified number of years preceding the purchase. Many of the English railways are subject to this last condition, but the option must be exercised within a certain time. In some countries the railways are at a certain date to become the property of the State

Right of pre-emption.

Terms of pre-emption.

without any payment whatever. This is the case in France, where the period is eighty years, but this period has in some of the French railways been extended in return for extra services or extensions given by the railways. In Russia also, where many of the principal railways are guaranteed by the State, the property reverts to the Government after a term of years, and advantage has been taken of the willingness which has been evinced to construct railways to shorten the term for railways constructed after a certain date. In all undertakings, of whatever character, the concession, if subject to such a condition, has the nature of a lease, and it is obvious that before a net revenue can be legitimately divided as interest, a portion of each year's profits must be set apart as a sinking fund to repay the capital invested. Where the terms of pre-emption are too onerous, capitalists are deterred from investing money. Thus electric lighting was much impeded in England because the right was reserved to the municipalities to buy up the works at their bare current value at too early a date; so that while the investors had all the risk of failure, the undertaking could be taken away from them, in the case of success, before the investors of the capital had received adequate compensation.

Reversion of railways to the State.

Sinking fund necessary.

See page 270.

See also TRAMWAYS, *page* 290.

CHAPTER III.

CONCESSIONS CONTINUED. THEIR CONSIDERATION BY CAPITALISTS AND CONTRACTORS.

CAUSES OF FAILURE.

THE general information which is necessary to the proper consideration of a scheme, the different kinds of concessions which may be granted, and the service demanded from the concessionnaires, have been described in the preceding chapter. The peculiar details of any particular scheme will be described in its own place in succeeding chapters. It now remains to be seen how proposals are likely to be viewed by capitalists, investors, and contractors, whose aid is sought to carry them out, and what are the objections which may be raised.

Contractors for foreign works.

The kind of persons to whom an enterprise should be submitted must depend upon the nature of the enterprise and the terms upon which it is to be offered. The majority of English contractors will not undertake contracts in a foreign country, and, indeed, for the successful carrying out of this class of undertakings, special qualities of mind are needed, such as a capacity for organisation, foresight in arranging the different stages in the work, a freedom from prejudice against what is novel, a power of adaptation to new circumstances, and abundant perseverance. There are, however, contractors who undertake work abroad as well as at home, and others who, having acquired special experience in the conduct of such works, confine themselves entirely to foreign contracts. The number of capable English contractors willing to undertake engineering works abroad is, nevertheless, limited, even where there is no reasonable doubt as to the security of the stipulated payments.

A contractor for foreign works may be considered more enterprising or more speculative than the contractor who works only at home; but the two have the same aim—the earning of money by contracts. To attain his purpose the contractor for foreign works has often to assist in the raising of money and in the financial arrangements generally; but he does so only as a means to the end, that end being ultimate remuneration in money. There are various reasons why the contractor is so often made the medium of financial negotiations. An assurance is given to the capitalist—which his own knowledge does not afford—of the feasibility of a project when it reaches him through the hands of the contractor; for although the capitalist will form his own opinion as to the ultimate profit of the speculation, yet the contractor, if he knows his business, will be qualified to decide whether the contemplated expenditure will be sufficient for the works; and, indeed, without passing beyond his own proper business, he may be willing to emphasise his opinion by taking the responsibility of completing the works for a specified sum of money. It is obvious that the capitalist will be the more ready to listen to proposals involving an investment of money, when this important condition is assured, thus leaving only the investigation as to profit. A contractor can often effect a sale of shares or transfer of securities where a promoter could not, because the nature of the undertaking may be such that the securities or shares acquire value only as certain works are completed, and on this point a contractor who is incurring personal liabilities can give satisfactory assurances which from a promoter might possess little value. And if the contractor's own profit depend on his carrying out his contract for the price named, his undertaking to do so must necessarily have weight. Capitalists often prefer to be approached in this way, and do not in the majority of cases, until this preliminary stage of estimated cost is passed, care to investigate schemes which are presented to them. The functions of capitalist and contractor are, however, often combined, as the demand for engineering works and the profits that have been obtained in them have created for foreign works a class of capitalist-contractors who apply their money entirely to such enterprises. But while the capitalist-contractor reserves to himself the power of retaining a permanent share in the undertaking, should it prove a good one, he generally differs from the ordinary investor in desiring to get back his money as soon as the work is finished.

Contractors and capitalists.

Sale of shares by contractors.

Reference has been made to the fact that since the time when railways were first introduced, numerous cases have occurred of a contractor taking part of his payment in shares, and making large profits by so doing; but, on the whole, such instances have been

See page 11.

Payments in shares.

exceptional. However, because of the examples of this kind that have occurred, and many others when the contractor has appeared to have accepted payment in shares while in fact relieved of them by previous arrangement with capitalists, there exists among those not well informed the belief that contractors for foreign works will be disposed to take payment in shares, obligations, or something that is not money. It may thus be accepted as a rule that contractors will not take anything but money in payment, except such securities, obligations, or shares, as they can at once, or within a reasonable time, sell or transfer to others for money. Nevertheless, contractors will listen to proposals of this kind, because—knowing by experience what conditions are necessary to obtain the capitalists' aid—it may be worth their while to take trouble in assisting such negotiations if success will bring them a profitable contract; but unless the nature of the undertaking and the rate of profit are such as will, in their opinion, attract outside investors, they will rarely proceed. Even if a contractor himself aids the enterprise by providing some of the capital, he will usually limit his investment to the amount of his estimated profit. The most conspicuous examples of failure among contractors have been when they have accepted as payment for work, securities or obligations which proved unsaleable.

See SYNDICATES, *page* 45.

Contractors assist in raising capital.

There are contractors who are so careful in this respect as never to meddle with finance, even to the extent described above, and who, while possessed of means sufficient even for large undertakings, use their capital only for the necessary advances of their business, working only for punctual and—as far as can be foreseen—secure money payments. When practicable it is desirable to employ contractors of this class, as they will generally be content with a less profit than those accustomed to speculative enterprises; and even where financial assistance is required, it may be possible to obtain the services of such contractors by dividing the business into two transactions, and obtaining the money in some other quarter. But where the security is at all speculative, or one which cannot be understood without special or technical knowledge, the capitalist will generally require that the whole business be placed in his hands. He will then either himself become the contractor—nominally or really—or ally himself with a contractor whom he knows and with whom he can arrange terms.

Prompt payment induces low prices.

There are different classes of capitalists who provide money for engineering enterprises, and according as any scheme is speculative, so does the number of those able and willing to assist become small and the terms onerous. To lend money for such undertakings does not come within the business of a banker according to the strict English interpretations of his functions, although indirectly, as will be seen, bankers do assist. For instance, a banker will lend money for carrying on the work, on the security of a contractor's plant and property, if he deem it good enough. In other cases the contractor or concessionnaire can offer as security, shares or obligations of the undertaking in question; these, however, a banker will not value according to the probable ultimate success of the scheme—although an assurance on such a point has some weight if other matters are satisfactory—but according as the securities are marketable. It is not the business of a banker to invest his money in enterprises, however remunerative, but to lend it for short and exactly-defined periods on good and marketable security. It is for this reason that bankers prefer to employ their money in discounting good bills of exchange, which satisfy these conditions, as the period of repayment is exactly defined, and the means of enforcing it in case of default are the most peremptory the law knows. Bankers, therefore, prefer to consider any bonds, shares, or obligations deposited with them, and which are not immediately saleable, only as collateral security, and look to the names of the borrowers as expressed on a bill or promissory note as the best assurance of safety. But while most English bankers will in theory define their functions strictly as above, there are few who have not at times found themselves burdened with unsaleable securities on which they have advanced money. They have been induced perhaps by their confidence in the borrower's ability and probity, at a time possibly when money was very plentiful and the ordinary outlets for it were scarce. Bankers can also often assist enterprises indirectly, because their business brings them in contact with speculative capitalists, and they may have clients willing to entertain offers of the kind.

Loans from bankers.

Shares as security.

Bills of Exchange.

The value of shares depends also on whether there are mortgages, or debentures, or bonds having priority. If works are constructed on land not fully paid for and on which the vendor holds a mortgage, then in case of non-payment of interest or of other default foreclosure may take place to the loss of the shareholders. Or, an issue of debentures or preference shares may greatly reduce or quite destroy the value of the ordinary shares. A contractor who without stipulation on these points has agreed to take payment in shares may find

Value of shares.

Depends on preference obligations.

See pages following index.

Debentures. *See pages 12 & 62.*

Effect of debentures on shares.

during the progress of his contract that the work he does only goes to swell the value of the security held by mortgagees or others having priority. As stated in another work by the present author, debentures are in England issuable by most companies whether "limited" or not, and in many the powers in this respect are defined and restricted by general or special Acts of Parliament. Some debentures are really only preference shares; and in regard to the capital or assets of the company which issues the debentures, though the holders might take precedence of ordinary shareholders in any winding up or realisation of the assets they would rank only with other and unsecured creditors. In most railways, and the rule is generally adopted by other well-constituted companies, the amount of debentures is limited to a certain proportion, generally one-third, of the paid-up share capital, the object being to give the debenture holders an assurance of the value of their security. Where a moderate proportion of this sort is ignored and sometimes even when it is observed, the money raised by debentures may have alone been beneficially applied and may afford the only assets. In the United States and some other countries the bonds (debentures) very generally represent the full value of the undertaking, and the shares, which rank after them, have only a postponed and problematical value. Great care is therefore necessary to scan the respective terms of all debentures, bonds, and shares.

Financial societies.

Speculative capitalists.

There are other capitalists—individuals, or financial societies—who go further than the banker, and lend money for longer and less exactly-defined periods on unnegotiable securities, and yet who do not care to enter directly into the risks of an enterprise. Cases of this sort arise where contractors are entitled to certain payments at a future date, or possess bonds or obligations which, though having little or no present value, as measured by any interest or income they may produce, will, when a certain time has elapsed, or certain contingencies have been fulfilled, become saleable. Capitalists will of course demand more than the ordinary rate of interest for advances of this sort; and besides the interest calculated in the usual way per mensem or per annum, often require a bonus or commission to induce them to assist. There are, again, capitalists little known to any but those who deal with them, who go further in assisting contractors. Such capitalists desire to be assured, first that those who have to pay for the works are solvent and honest, and then that the contract price is such as will leave sufficient profit. On this second point the contractor has, by furnishing details of anticipated expenditure and receipts, to afford an opportunity for verifying his calculations. Capitalists of this sort will sometimes be content with no other security than that of the contract itself, but will generally take care to have a first charge upon all the profits, and will stipulate that they be made cognisant of all expenditure and receipts. They become, in effect, preference partners in the enterprise; but, while taking the first share of the profits, keep in the background and incur no liability or risk beyond the sums they have advanced. Capitalists will seldom assist in this way except where the contractor is able to provide some of the capital, either in money or plant, and the capitalist has the first charge on the earnings of the joint contributions. Very often the profits of a contract are so large when the works are carried out by a skilful and energetic contractor, as to allow ample profit after the capitalist has had his share; but not unfrequently a sanguine contractor, in his eagerness to obtain the aid of a capitalist, will engage to pay so highly for it as to have little or nothing left for himself, even on what is *per se* a profitable enterprise.

Preference partners.

Syndicates.

The earlier proceedings in connection with a new undertaking are often conducted by a "Syndicate," or group of persons (thus designated by a modern adaptation of an old word), who, wishing to further one common object, combine for the purpose, but who are not, in the ordinary sense, partners. This means is adopted by persons unable or unwilling singly to provide all the necessary money, but who think it worth while to speculate to a limited amount. A syndicate is very often formed merely to provide money for preliminary expenses, and with no intention of providing capital for the undertaking. For instance, this course is adopted very often where a certain expenditure must be incurred before a company can be formed or works commenced; and the members of the syndicate thus take upon themselves the speculative risk (which it might be impossible, or improper, or illegal to incur as trustees for shareholders) of losing all the expenditure in case the undertaking fails to proceed. In such cases the syndicate may be said to take the place of a promoter. Sometimes a syndicate will even engage to provide all the capital for an enterprise, but if the members retain their interest in the undertaking, they may be more correctly designated as a company. But a syndicate which provides the

See page 22.

capital generally does so merely to ensure the commencement of the undertaking, and even for this purpose the members often employ their credit only, rather than actual money. For instance, if £50,000 be required for some joint-stock undertaking, ten persons of established credit may guarantee to provide by themselves, or their friends, £5000 each, in the hope and with the intention of transferring to friends or clients the proportion of shares which they have guaranteed to take. A contractor who has agreed to take payment for his work in shares, or a promoter who is interested in the formation of a company, instead of risking all by an appeal to the public for subscriptions, the failure of which might much prejudice his scheme, sometimes prefers to invite a combination of capitalists to take all or a large number of shares in the undertaking at a reduced—or what may be termed a wholesale—price, before they are offered to the public at their full price. The members of the syndicate then dispose of the shares from time to time at the full price, as there appear buyers for them. This method of forming a syndicate may also be adopted with advantage when an existing undertaking requires more capital at a time when the money market is unfavourable for a public subscription. From this point of view a member of a syndicate is valuable in proportion to the number of persons whom he can influence; but as, in times of excessive speculation, investors have been often induced by those whose advice or opinion they trusted, to embark in enterprises which prove fallacious or disastrous, syndicate combinations have in such cases been greatly discredited. Fairly conducted, however, they are legitimate and convenient.

Capital provided by syndicates.

Syndicates discredited.

There are frequently cases in the English Colonies where profitable enterprises are hindered for want of funds, which cannot be obtained locally even where there is tangible—though not always immediately saleable—security in the shape of land and other property. The circumstances may be such as to warrant the payment of interest much above that usual in England, and yet such security fails to attract English investors. But just as water will, even through indirect channels, find a level, so English capital finds its way through the medium of colonial banks and financial societies which are established in England. Such societies can offer a higher rate of interest for deposits than is usual in England, and they pledge also the security of their own subscribed capital. The difference between the rate at which they borrow and colonial rates allows a consider-

See page 14.

Colonial Banks.

able margin of profit to the society, colonial enterprise is encouraged, and the English investor deems himself secure. The chief risk lies in the nature of the securities held by the colonial banks, and the suspension of payments by Australian banks in 1893 is an example.

Promoters' credentials.

If a promoter has a scheme thoroughly matured, and is prepared to supply the information described in the preceding and following pages, he will have little difficulty in obtaining at any rate consideration of his scheme. He may possibly be able to produce only the necessary technical and local information, and, as regards money, may be desirous of learning the kind of terms on which capitalists will assist him. If he is furnished with proper credentials and full powers to treat, and the enterprise is not of a great or exceptional kind, he will have no difficulty in obtaining offers from competent capitalists and contractors. But if the promoter has limited powers and can do no more than send home to his principals for consideration any offer he may obtain in England, he will find capitalists and contractors indisposed to commit themselves without some guarantee. Contractors are always averse to giving tenders which are to remain open for an indefinite time, and which may possibly be disclosed to competitors. An experienced contractor having made an estimate of cost, or a financier having calculated the terms upon which the enterprise may be carried through, possesses important information, which in its way is, when imparted to the promoter, as valuable to him as an engineer's design, or any other essential part of the scheme. The promoter will, therefore, have to satisfy those who have helped him that their offers will be fairly dealt with, and that, if the terms are reasonable and within the means at command, they will be accepted.

Guarantees required.

Even where the honour and good faith of the promoter are undoubted, he may not always be able to prevent unfair dealings with the offers he has transmitted when they have reached a foreign country. Since 1860, hundreds of thousands of pounds have been expended by English contractors in making preliminary surveys, investigations, and even working-plans, which have produced for them nothing in return, but which have been eventually handed over to the use of others. It is not to be inferred from the above caution that contractors and capitalists object to competition; but it is a reasonable stipulation on their part that they be made aware of it from the commencement of the negotiations. Contractors wish also

Unfair preference.

to be satisfied that their competitors shall have no unfair preference, and that their own estimates of cost shall not be obtained merely as a means of beating down in price other contractors, to whom it is intended from the commencement to offer the concession.

Contractor's surveys.

In some cases the promoter is unable to furnish sufficient information upon which to base an estimate of cost, and, as referred to previously, he may be asked to share in the expense of obtaining it. Even where full information is afforded, the contractor will generally require to verify it. If this involve a journey to a foreign country, and the further expenses of a survey, the contractor will sometimes stipulate for the option of taking the concession on stated terms, or for remuneration in case the business falls through. There are cases where no such stipulations are made, because the anticipated profits of the enterprise and the likelihood of success are sufficient to induce a contractor to incur considerable trouble and expense in preliminary surveys and negotiations without any guarantee. These are all matters which the promoter has to consider, and for which no general rule can be made.

Schemes fail of adoption.

Those who are interested in the furtherance of some new enterprise, often suffer disappointment by failing to obtain the adoption of their scheme, or that assistance in carrying it out which they seek. As to be forewarned is, to some extent, to be forearmed, it may be appropriate here to indicate some of the causes of such failure.

Promoters too sanguine.

Flaws discovered.

See ERECTION OF BRIDGES, *page* 136.

Promoters of new undertakings abroad are generally too sanguine concerning the aid which they may obtain from English capitalists. Having seen or heard of the apparently similar enterprises which have been so aided and carried to success, they are perhaps unaware of, or attach too little importance to, the much greater number of schemes which have been laid before capitalists, and declined. To reduce as far as possible the chances of failure, the first and most important point is to afford every information at the outset, even of what may be considered the weak points of the enterprise, because if these weak points are left to be discovered by investigation and inquiry, it is not unnatural for those who discover them to doubt the good faith of the promoter who has concealed them, and to suspect that there may be other flaws also. The promoters or others locally interested in the success of a scheme may often do much to render it acceptable to contractors and capitalists by eliminating from it many risks which they themselves may better—because of their greater local knowledge—undertake. It may of course be considered preferable that contractors should undertake all the responsibilities; but it must be remembered that there are two parties to a bargain, and that the more onerous the conditions and the greater the difficulty of measuring the risks, the less will be the number of those who will entertain them.

Conditions of success.

An engineering enterprise, to be successful, must satisfy certain technical and economical conditions; and these demand entirely different kinds of investigation. An engineer to whom a scheme is submitted may find that it is feasible, and that as no experimental methods or extraordinary works are required, the risk will be but small; the calculations of outlay and profit may also appear to him reasonable, and he gives to the scheme the sanction of his name. Yet there may be economical reasons, which to a financier or economist, as eminent in his way as the engineer, will show the unsoundness of the undertaking. The fault is sometimes on the other side. A scheme is submitted to a financier who, uninformed on technical matters, may accept as correct the plausible but incomplete engineering details, and on such a basis may decide that the scheme will be safe and profitable; while in reality there may be some flaw—perhaps even of a rudimentary kind—which bars the way to success. Were it not that failures frequently occur for these reasons, the need for fuller investigation would appear too obvious to be mentioned.

Financial flaws.

Engineering flaws.

But even where the feasibility of a scheme, both in its technical and economic aspects, appears certain, it often fails for some secondary reason to obtain support.

Time not favourable.

The time for introducing the scheme may be unfavourable.—There occur periodically seasons of distrust in the financial world, when, owing to recent panic, failure, or other causes, almost every kind of new undertaking is looked at with suspicion. This state of things may even produce a superabundance of capital ready for investment, but which the owners may be afraid to invest, and the apparent anomaly presents itself of a plethora and a scarcity of money at the same time. It is obvious that distrust will produce this double result.

Similar schemes to the one presented may have recently failed, or, to take an extreme case, the public mind may have been prejudiced by

Schemes discredited.

the recent exposure of actual mis-statements or impositions in regard to them. And, further, even when the scheme is a sound one, and when the capitalists before whom it is laid for consideration are able to distinguish it from others which have proved unsound, they may decline to deal with it, because if the enterprise is to be offered to the public for subscription, it is generally useless at such a time to argue against the public distrust. The fact must be accepted, and a more favourable opportunity awaited.

Scheme too large.

The undertaking may be too large.—In the case of public works of great magnitude involving a very large expenditure, and where the assistance of the public has to be obtained on a great scale, the affair demands special treatment, and if undertaken only in the manner of ordinary enterprises it may fail. The feasibility and profitable nature of the undertaking may have to be explained with exceptional clearness to the public mind, the condition of the money market may have to be closely studied, and special legislative guarantees may be found necessary. Where the enterprise is novel and speculative as well as large, it seldom can be successfully started till the mind of the public has been educated to receive it, and this is sometimes the work of years. The Suez Canal, the Panama Canal, the Manchester Ship Canal, and the Tunnel under the English Channel are extreme cases of this kind. It will be found that those whose usual business is to negotiate undertakings of an ordinay kind will hesitate to engage in these special ones, which promise no practicable or profitable results to themselves within a reasonable time, even though they may be convinced of the ultimate success of the scheme and of its public advantage.

Examples.

Scheme too small.

The undertaking may be too small.—There are unavoidable expenses incurred in raising money from the public for a new undertaking, and these are generally much greater in proportion for a small than for a large amount, and they will sometimes entirely swamp the enterprise. Small undertakings are most successful when carried out by a limited number of capitalists, who subscribe the necessary funds by private arrangement without any expenditure for promotion, and who thus insure that all the capital will be applied, without deduction, to the real end in view. As in the preliminaries, so also in the carrying out of the work, small undertakings in foreign countries cannot be profitably managed from a distance. In every foreign enterprise,

May succeed by private enterprise.

whatever be its extent, if it is carried through by British capitalists or contractors, certain organisation and management are necessary. The trouble, expenses, and responsibilities attendant on these may, in the case of small undertakings, be so great in proportion to the expected profit as to deter from the enterprise those who but for this would engage in it. Capitalists and contractors who usually undertake such works cannot or will not set in motion for small affairs the machinery necessary to proper management. If, for instance, works costing £10,000 or £20,000 are wanted in a distant country, there will sometimes be far more difficulty in getting capitalists or contractors to undertake them, than if the cost were five, ten, or even twenty times as large. This objection will have weight in proportion to the remoteness of the country and the want of security there. Cases of this sort are eminently those for local enterprise. Engineering aid may be obtained in England, machinery and plant purchased, and experienced superintendents engaged at salaries to assist, but it is not easy to find anyone in England willing to take all the responsibility up to completion. Sometimes advantage may be taken of the presence, in the distant country, of English contractors, who happen to be engaged there in other works of greater magnitude, and who may be willing to use their staff or plant for the smaller enterprise. Sometimes, also, English contractors accustomed to small affairs, and who know something of the country, may undertake the works, because, by giving their undivided personal attention to them, they may make a good profit, when, if loaded with the expenses usually attending deputed management, the enterprise might be unremunerative. Promoters of small undertakings may sometimes be fortunate enough to find contractors in England who have some of their staff disengaged, and who, to retain the services of experienced men, may be willing to employ them temporarily on smaller works. In the larger British Colonies, local contractors are able to undertake works of magnitude and importance, and where the money for public works is provided by the State, there is no need for outside aid.

Expenses of management.

See BRIDGES, *page* 136.

Local contractors.

The estimated profit may be too small.—There is no standard by which the sufficiency of the return offered by any enterprise can be measured. The rate of profit which will induce capitalists or contractors to undertake works, increases with the risks, the trouble, and the distance from home. According as the difficulties appear great, so will the number of persons willing as well as able to

Profits too small.

contract become small, and those who are willing naturally demand terms advantageous to themselves. If the profits gained in previous

Profits of previous ventures compared.

contracts of a similar character are cited as a reason for lower terms, due allowance must be made for differences, however slight, which attend the new enterprise, and to the fact that risks which have been avoided or overcome in the one case, have yet to be encountered in the other. It may be that the amount of profit gained in a previous enterprise is felt to be insufficient, and in itself is an argument against, instead of for, undertaking another on the same terms. There are generally differences of opinion between buyers and sellers, and after every argument has been used, it of course remains entirely at the discretion of the contractor to adhere to his own terms. The matter is then finally determined by the ordinary rules of supply and demand, and if competition be limited by the nature of the undertaking, or for other reasons, the contractor will naturally be somewhat guided by the necessities of the buyer, and will hardly forego voluntarily the maximum price which he feels the buyer is willing to pay. Not only the price but also the terms and conditions are determined by these same considerations.

Postponed profits.
See also RETENTION, *pages* 38 & 453.

The profits may be too long postponed.—Even where the profit which is ultimately to be gained appears sufficient, too long a postponement of it may disincline capitalists or contractors from an enterprise. Although the estimate of cost may have included interest on capital during the period of construction, or of waiting, those who engage in public works like to get the principal money itself back again as soon as possible, so as to use it again. Even if the necessary capital is to be raised by appealing to the public for subscriptions, the postponement will have the same deterring effect, and will reduce the number of contributors.

There are, of course, capitalists who will wait a considerable time if the profit ultimately to be gained appears sufficient and well enough secured; but there are others—and these the majority—whose assistance can be obtained only in those enterprises where there will be a return within a reasonable time. If, for instance, the capital be held in shares, whatever may be the nominal rights of transfer, shares on which the profit is merely prospective are not

Saleable shares preferred.

always easily saleable. Even though there be risk of great fluctuations in price, speculative investors will often prefer what they can always sell at some price to that for which it is difficult to find any market. As pledges or security, bankers always prefer such saleable shares. It need hardly be mentioned that of only a small proportion of the undertakings in which capital is invested, are the shares quoted on the Stock Exchange, and saleable at all times. *See page 43.*

Vague concessions.

The terms or the advantages of the concession may be too vague or speculative.—On this rock of difficulty a large proportion of schemes proposed by sanguine promoters split at an early stage. Indeed, it is astonishing how persons who have any claim to business capacity can expect consideration for some of the immature, vague, and even absurd schemes which they bring forward. Some explanation may perhaps be found in the fact that the scheme in question is one entirely outside their own experience; and promoters who may be shrewd enough in their own proper business may be ignorant of the rudimentary objections which are fatal to their new scheme. Examples of this vagueness are often furnished by schemes for the purchase of a new patent, or other speculative monopoly. Large gains have resulted from such, but as not one patent in fifty repays the inventor, the advantages offered must be very apparent, or at least capable of very easy proof, and the profits must be considerable, to induce capitalists to rely upon them.

Payments vaguely defined.

Sometimes the vagueness lies in the definition of the payments. The following may be given as an instance: A promoter will offer some new enterprise to a contractor or capitalist, who is to accept, in return for his aid, remuneration, all or in part, in shares, debentures, or obligations. Now, it is possible that the scheme may be so sound that such remuneration, if properly arranged, may be sufficient. But it is obvious that the value of shares or debentures depends upon various considerations, besides the mere nature of the enterprise. The jurisdiction under which the undertaking is to be carried on; the amount of capital to be raised; the proportion the capital will bear to the cost and profits of the undertaking; the proportionate amount of shares and debentures; the priority, if any, of one kind of share over another, or of debentures over both; the nature of the guarantees; the names and reputation of the persons who are to manage the affair; information on these and a variety of other points is essential to a proper assessment of value. As has been referred to already, it is primarily the duty of the promoter to arrange these matters. If he does not, he should acknowledge his position at the outset, and at any rate be prepared with such information as will,

See page 23.

See page 41.

See page 22.

Inchoate schemes.

if the enterprise is a good one, enable those who have experience in such matters to prepare a complete scheme. But too often the promoter professes to have a very complete scheme ready; and it is only by an exhaustive series of questions that its inchoate condition is discovered, when the prospects of the enterprise are discredited accordingly.

Insecurity.

Repudiation.

Corrupt officials.

Fallacious securities.

Disputed accounts.

See page 30.

Confiscation.

Insecurity.—Apart altogether from the ordinary chances of profit or loss, which according to its nature accompany every enterprise, an earlier question of security arises. There are countries—unfortunately not unknown to British enterprise—where all property is insecure. Liability to war or civil commotion, during which works may be interrupted or property destroyed; the despotic nature of governments, or sudden changes of rulers, are causes of insecurity One set of ministers may repudiate the acts and obligations of their predecessors, or obligations which were originally promised in gold may be paid in depreciated currency. A natural want of honesty; a low moral tone in the people; corruption in officials or tribunals; jealousy of foreign interference, are other causes. Taxes from which an undertaking has been directly or by implication exempted, may be inflicted; and *ex post facto* legislation, nominally general in its application, may be aimed specially at the foreign capital, which has ventured within its power. Sometimes, through poverty or greed, or sheer dishonesty, guarantees are repudiated; and though stern necessity is often pleaded as an excuse for such injustice, the injury is none the less. Even where a supposed security has been given, as by liens on property, or special hypothecation of revenues or taxes, it may prove impossible, from partiality in the law or weakness of the executive. to foreclose, and the capitalist may find himself without remedy. Sometimes, while no direct repudiation may be attempted, the conditions of a concession, the meaning of an agreement, or a statement of accounts may be disputed, and advantage be taken of the dispute to refuse payments which are due. Many such cases have occurred in countries which would not venture to hold back the interest on a public loan, and it is for this reason that public loans, which pledge the credit of a country unconditionally, are more favourably received by capitalists than conditional guarantees. Countries where wrongs of this kind are perpetrated of course lose their credit, and have to pay dearly for it in the future. Capitalists are sensitive of anything savouring, however remotely, of confiscation, and although the temptation of high gains may induce speculative investors, resting on fresh assurances, to enter into new enterprises, the sources from which capital can be obtained are for such countries greatly narrowed, and the difficulties in the way of promoters are immensely increased. Even where no previous repudiation has damaged the credit of a country, and there is no reason for doubting the good faith of its rulers, intending investors should take pains to ascertain the resources available, and to see that the obligations incurred are really within the means and power of the people to fulfil.

See page 25.

Promoters' claims.

Extravagant demands.—Reference has been made to the price or consideration which has sometimes to be paid for a concession. Foreign enterprises are in the majority of cases introduced to English capitalists by promoters who seek a profit from the transaction; and behind these promoters may be others also who have to be conciliated or paid. The skill and trouble which have been bestowed upon a scheme in its earlier stages may have been as necessary and as legitimate as the actual carrying out of the works; and payment for these services may be claimed with equal fairness. So also, as in other business transactions, commissions may have to be paid to those who aid in bringing together the various parties to the transaction, or who, by their experience in such matters, know what to do or avoid in steering the undertaking to maturity and success. More than this, the undertaking may be of such a remunerative nature as to entitle those who dispose of it to a distinct and considerable profit. It is obvious that no rule can be laid down on such a matter. But as in regard to new enterprises there is often no fixed standard by which to measure value, and as the promoters may have, in the first instance, to name an arbitrary price, there is often a not unnatural tendency to take advantage of such a position, and to demand too much. Where the interests of the promoters lie in this direction, it is not difficult for them to prove, at any rate to their own satisfaction, that the price and terms they demand are well within what the profits of the enterprise will afford, and are altogether justified by the merits of the case. A seller naming his own price often has these views.

Arbitrary prices.

Extravagant demands.

It is evident that if an undue load of charges be put upon an enterprise, the effect must, sooner or later, be disastrous to those who embark capital in it. Examples may be seen in all directions of railways and other public works, with moderate working expenses, with a net revenue amply sufficient to pay remunerative interest on the real cost of the undertaking, and yet which afford little or no dividend to the proprietors. It has been discovered too late that so much money was squandered in preliminary expenses, in extravagant **Excessive capital.** outlay, heavy commissions or corruption, that the nominal capital is far in excess of what would have been necessary under honest and capable management. To meet these charges the capital has been **Watered shares.** so extended, or the shares so "watered," that the revenue, when divided, will only pay a very small rate of interest; or preference obligations have been incurred to such an extent that no dividend at all is left when the prior claims have been met. Capitalists are not blind to these contingencies, of which there is much past experience to warn them; and although occasional success in evading scrutiny may encourage promoters in extravagant demands, the majority of schemes so treated deservedly fail. Where, however, promoters have a sincere and well-founded belief in the value of an enterprise, they can obtain an ample share of profit, and, at the same time, give proof of good faith by deferring their own claims till those of the other investors have been met. Arrangements of this kind have been already referred to.

CHAPTER IV.

RAILWAYS.

THE amount of capital expended in the construction of railways equals or exceeds that invested in all other modern public works; and there are engineers, capitalists, and contractors who confine themselves almost entirely to this one kind of enterprise. But in considering the conditions necessary for the successful carrying out of a new railway scheme, as well as of any other engineering project, it must be borne in mind that, however necessary or desirable the work may be to the development or prosperity of a country, capitalists whose aid is invited will look at the enterprise solely from an economical point of view. If a railway is likely to produce enough revenue, directly it is opened, to pay a fair interest on its cost, this likelihood affords a *primâ facie* plea for obtaining the money for its construction. Subject to its feasibility, and the other general conditions alluded to in the preceding chapters, it is obvious that the probability of an immediately remunerative return is the essential preliminary question to be settled; and the burden of proof of this lies on the promoters. Still, if this question cannot be answered satisfactorily, it does not follow that the railway should not be made. There may be so many secondary, or indirect, advantages to be gained that the inhabitants, either directly or through their Government, or some Local Authority, may give such contributions, subsidies, or guarantees as will compen-

Conditions of success.

Interest on cost.

Secondary advantages.

sate for the deficiency, and make the enterprise a safe one for the outside capitalist. Various arrangements of this kind have been already alluded to.

See pages 24 to 36.

Calculations of profit.

In calculating the probable profits of a railway, there are three principal factors in the estimate:—

I. The Cost of the Railway.
II. The Expenses of Working and Maintenance.
III. The Revenue.

Calculation of cost.

I. *The Cost of the Railway.*—The calculation of cost depends on the special nature of each case. In settled countries the primary expenditure is that for land, in the price of which there is the widest divergence. In sparsely peopled countries or colonies, whose development depends on the construction of railroads, not only may the land actually needed for the line be given gratis, but additional land contiguous to the line of route, so that those who embark money in the construction may share in the enhanced value of the land due to their enterprise. This contribution may, indeed, be a necessary aid to the raising of money on special bonds created on the security afforded by the prospective land value. In England either the average rate of interest paid by railway undertakings is much less than it would be if the land had been obtained on equitable terms, or, in order to pay a fair interest, the rates of freight are higher than they need have been if the cost of the land and its expropriation had been less. But legislation with regard to railways has been so conducted that not only have excessive prices been demanded and obtained, but extravagant compensation has been allowed, where, instead of the injuries pleaded, great advantages have been certain to accrue from the railway.

Purchase of land.
See pages 2, 16 & 26.

Width of gauge.

The amount of land required depends, first, on whether a single or double line is required; secondly, on the width of gauge; and, thirdly, on the nature of the works. As almost everything connected with a railway—land, works, and rolling-stock—is to some extent determined by the gauge, which may almost be termed the key-note of the project, the subject demands careful consideration. The gauge of 4 ft. 8½ in., which was adopted first on English railways, and which, as the "standard gauge," now generally prevails in Europe and the United States, was that of the existing vehicles on

Standard gauge.

common roads; and, although the precise dimensions were accidental, being those of the colliery tramways which were the immediate precursors of railways, it is useful to remember that the ordinary custom in regard to the width of carts and carriages was the outcome of long experience, and that such vehicles had been found wide enough, but not too wide, for the safe and convenient conveyance of passengers and goods. And, after many years' experience of railways, both wider and narrower than the original standard gauge, it is found that while a wider gauge is unnecessary, a narrower one—though sufficient for railways of particular kinds, such as will presently be described—does not fulfil all the conditions necessary for an important line. If the matter were open for discussion on its merits, probably 5 ft. would be the width chosen by English engineers, the slight increase over the present standard being advantageous in the designing of locomotives, especially those with inside cylinders. But as uniformity is the chief consideration, the standard gauge may be accepted without further question. For many years after the establishment of railways in England it was so accepted in the majority of cases; and, where any difference was made, it was in the direction of a wider gauge. For the present purpose, the following may be stated as axioms agreed to by the great majority of railway engineers:—

Gauge of ordinary vehicles.

See page 68.

(*a*) There are no peculiar merits in the standard 4 ft. 8½ in. gauge which, apart from the advantages of uniformity, make those exact dimensions the best for railways.

Break of gauge.

(*b*) The inconveniences and expense attending the break of gauge are so great, that without special and weighty reasons, no new gauge should be introduced into a district or country where railways of another gauge may be expected to come in contact. In the United States and Canada great expense has been incurred in reducing the various wide gauges to the standard, and in Australia the diversity of gauge in the separate Colonies will render a similar expenditure necessary in the early future.

Standard gauge preferable.

(*c*) Where the traffic of a country is great or is likely to become so, and where the necessary money can be obtained without too great a burden on the community, it is better to avoid, even in inaugurating railways, any gauge much less than the standard gauge: and, as there are several minor advantages in having railway stock and appliances similar to those in other countries, and therefore, more easily purchased, the standard gauge should be preferred. The conveyance of large guns, large boilers, road vehicles, thrashing-machines, and similar bulky articles, is not easily accomplished on a narrow-gauge railway; and if, to maintain the same loading gauge, wide and lofty trucks are built on a narrow wheel-base, the centre of gravity in the vehicles would almost necessarily be high, and they would not run safely. The same width of land, tunnels, and bridges as for the standard gauge would also be required. Moreover, so long as locomotives are wanted of the strength and speed now adopted on the principal lines, nothing much less than the standard gauge will afford sufficient strength and at the same time allow convenient access to all the working parts.

Reasons against narrow gauge.

See LOCOMOTIVES, *page* 637.

Narrow gauges.

(*d*) Narrow-gauge lines of from 2 ft. to 3 ft. 6 in. are sufficient for very considerable traffic; those not less than 2 ft. 6 in. gauge being sufficient for a maximum speed of 20 miles per hour; those of 3 ft. for 25 miles per hour; and those of 3 ft. 6 in. for 35 miles per hour, with ease and safety.

Cheapness obtained.

(*e*) The saving in land by the use of narrow gauges is inconsiderable; but sharper curves are feasible, and the saving in works and rolling-stock is considerable, say 20 per cent. and upwards, according to the weight of the locomotives and the corresponding strength of the permanent way.

Cost of railways.

See page 63.

Cost of railway, how determined.

RY. EQUIPMENT, *page* 659. FLUCTUATIONS IN PRICES, *page* 443.

There is no fixed rule for the cost of railways, a range of from £2000 to £20,000 per mile of single line standard-gauge indicating the wide diversity in actual practice. The actual cost depends on three main considerations: First, on the nature of the ground which may in one case allow the railway to be laid as a surface line with little or no expense for earthworks, and in another may require expensive cuttings, embankments, bridges, or tunnels. Secondly, on the strength, capacity and equipment of the line. Thirdly, on the prices current for rails and other materials. In regard to the second of these points, the rail track is the essential condition, and this can be given very cheaply, unless considerable earthworks or expensive bridges are required. In a newly settled country much of the outlay usual in European railways may be omitted as non-essential to the immediate object in view. Thus the pioneer railways in the United States of America have been cheaply made, not only because land has been obtained free of cost, but also by the omission of ballast, fences, buildings, signals, and over-bridges, and by using light rails. Although a ballasted road is necessary to smooth running and high

Pioneer railways.

Ballast omitted.

speed, the cost is so considerable that the advantages of railway communication may be obtained at moderate cost by leaving the ballasting till the traffic has developed and funds are available. But there is so much risk in running trains on an uneven road that a saving in the weight of rails would even be preferable to having no ballast at all. The gauge of the line should, from the commencement, accord with that of the neighbouring railways, whose rolling-stock may have to run upon the new line; and although a considerable saving may be made by using light rails, yet they will rapidly deteriorate if heavy engines from neighbouring lines pass over them, the efficiency of the line for through traffic being thus greatly hindered. The chief use of fences is to prevent animals straying on to the line; and where, as in America, fences are universally omitted except in the neighbourhood of important towns, the risks of collision are minimised by using strong headlights on the engine, so illuminating the track as to show any obstruction, and by the pilot or "cow-catcher" in front of the engine, which throws off any animal which comes in the way. Signals are obviously of little use where only two or three trains run per day; and until the traffic grows, the use of the telegraph and the protection by flagmen of the trains while standing are found sufficient for safety. Buildings are only accessories to a railway; warehouses may be built as traffic demands it; while most of the business of the passengers' tickets and baggage may be managed by the conductors in the cars, and the actual office work may be carried on in small cheap buildings. The raised platforms, waiting-rooms, and other accessories usual on European lines, do not necessarily pertain to a train service, and can be added afterwards. Under-bridges are of course necessary from the commencement to carry a railway over rivers and ravines, and though economy is sometimes sought by constructing rude or temporary bridges, such cheapness is unadvisable, and involves outlay and inconvenience at an early date. But by omitting over-bridges for road crossings, a considerable saving can be effected, not only in the actual cost of the bridges, but in the approaches which they require. Against this, however, it must be remembered that as towns grow up along a railway, there will be considerable outlay for gates and watchmen; and later on the passage of express trains through towns is retarded by municipal rules limiting the speed, or, as has taken place in the large cities of the United States, the railways have, at great cost, to be raised on viaducts. In a newly settled country, how-

Cheap construction.

Fences omitted.

Signals. *See page* 676.

Station buildings. *See page* 683.

Under-bridges. *See page* 149.

Over-bridges omitted.

Speed limited.

ever, the inconveniences appear too remote to justify such expense at the beginning to avoid them.

Working expenses.

Betterment.

Railway bonds. *See pages 12, 32 & 44.*

While it may be expedient, and indeed necessary, to adopt some or all of the economies stated above, it must be borne in mind that cheap construction involves a higher ratio of working expenses than where everything is made strong and complete from the commencement. The average cost of working the United States railways in 1896 was 70 per cent. of the gross receipts, as against an average of 56 per cent. in Great Britain. Moreover, where, as in the United States, it is endeavoured to strengthen and improve cheap railways out of revenue as traffic increases, shareholders are often tantalised by receiving small dividends, while the accounts show a large net revenue after the payment of maintenance and running expenses. Much of what would appear to be a balance available for dividend has been expended in ballasting, on heavier rails, stronger bridges, station buildings, and other forms of "betterment." So long as the interest on bonds can be met, those who control the management may deem it advantageous to strengthen the line, and give a future value to the shares. The relation of bond to share capital, and the fact that the management is largely in the hands of those who have not provided the funds for construction, are the circumstances that mainly explain these apparent anomalies.

Extraordinary works.

Cost of tunnels.

Lining tunnels.

When railways cross hilly country, or where the cuttings and tunnels are numerous or of heavy material, or where expensive long-span bridges are required, the cost rapidly increases. The cost of tunnels for a single line of standard gauge may be stated at £25 per lineal yard and upwards, depending on the nature of the material to be excavated, on the masonry or other new work to be performed, and on other circumstances. A tunnel that does not require lining with brickwork, or only a partial lining to arch over sloping sides as is possible in rocky strata, is cheaper than a tunnel through softer strata that requires lining. The second Ampthill tunnel (double line) on the Midland Railway, made in 1893–5, through slippery clay strata, cost £60 per lineal yard. From £40 to £90 per lineal yard are limits of cost wide enough to include the great majority of double line tunnels; but in exceptional cases these rates of expenditure have been greatly exceeded. The Kilsby tunnel, 1⅓ mile long, with a double line of standard gauge, on the London and North-Western Railway, which had to pierce a stratum of quicksand, and in which continuous pumping on a great scale was necessary, cost

£125 per yard, and even this sum has in a few cases been exceeded. The Mont Cenis tunnel cost £225 per yard, the St. Gothard tunnel £143, and the Arlberg tunnel £108 per yard.

Expensive tunnels.
See also page 171.

The expenses above referred to for embankments, cuttings, and tunnels, which are necessary in a hilly country for the construction of a railway with moderate gradients, may in many such cases be avoided if steep gradients or sharp curves could be permitted. But the width of gauge prevents sharp curves, and on the main lines of the principal English railways curves of less than 1650 ft. (25 chains) are considered unsuitable for heavy trains running at high speed, and even on branch lines it is always considered desirable to avoid any less radius than 15 chains. Where there is a less radius (and there are on some English lines sharp curves of 12 and 10 chains) a reduced speed becomes necessary, although the modern improvements in bogie-frames for engines and rolling-stock ensure smoother running than formerly. Steep gradients add so greatly to the locomotive power required, that even at an increased first cost engineers endeavour to avoid them. Generally speaking, the gradients on English main lines are seldom steeper than 1 in 90, and some of the more important railways have sections of 100 miles with no gradients steeper than 1 in 200. Some even of the best lines, however, have a few exceptional gradients of 1 in 50 to 1 in 70, while in some rare cases both passenger and goods trains are drawn by locomotive power up 1 in 37. There are also mineral railways where inclines as steep as 1 in 19 are overcome by locomotives pushing the trains, and 1 in 15 may be taken as the absolute limit for locomotives dependent in the usual way for their tractive force on the adhesion to the rails. For gradients steeper than 1 in 15 special kinds of locomotives, fixed engines, or other exceptional apparatus become necessary.

Standard gauge involves heavy works.

Radius of curves.

See pages 691 *&* 711. LOCOMOTIVES *and* ROLLING-STOCK.

Gradients.
See also TRAMWAYS, *page* 301.

Steep gradients.
See page 694.

A single line of the standard (4 ft. 8½ in.) gauge, with rails 60 lb. per yard, with embankments and cuttings averaging 3 feet, but with little ballasting, will cost about £4,000 per mile, exclusive of land and rolling-stock. With ballast 15 in. to 24 in. deep, rails 70 lb. per yard, and station buildings, the cost rapidly increases to £6,000 per mile. But in Great Britain and on some of the principal railways of the United States much stronger lines are constructed, with rails of 80 lb. to 90 lb., and in a few cases even 100 lb. per yard.

Cost of railways.

See also page 68.

Even leaving out of question the enhancement of cost which has so often in England resulted from Parliamentary contests, extravagant compensations and inequitable payments, some single-line railways

See page 8.

Cost of double lines.

Equipment of double line.

have, from the nature of the works alone, cost over £20,000 per mile. The cost of a double line will add approximately from 50 to 75 per cent. to the rates per mile above stated; but as the advantages afforded by a double line over a single line consist in the convenience, regularity, and safety of working, as well as in the increased capacity for traffic; and as the cost of equipment—station fittings and rolling-stock—depends mainly on the traffic, the additional cost of equipment for a double line does not follow in the same proportion, and unless the traffic be much increased, from 10 to 30 per cent. would cover it. But as a double line worked to its full extent will carry much more than double the traffic of a single line, the expense of rolling-stock may in such a case also be more than doubled with profitable results.

Quantity of land required.

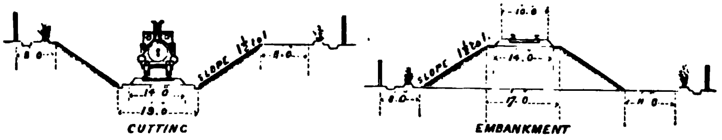
See diagrams below.

Depends on slopes.

Land at stations.

See page 684.

It is usual to state separately the cost of land and of rolling-stock. The quantity of land required for a mile of railway depends upon the width as determined by the depth of cuttings and height of embankments. Assuming an average depth and height of 3 ft. and a slope of 1½ to 1 (which is that usual for alluvial soil), from 5 to 6 acres will be required per mile of single-line standard-gauge railway made in the manner usual in England. For each foot deducted from or added to the average depth and height, one yard in width or 1760 yards per mile (about ⅜ acre) must—if the same angle of 1½ to 1 be maintained—be deducted from or added to the acreage given above. These quantities are exclusive of land for sidings and stations. It is always advisable for a railway company to secure surplus land at stations, because such land will be invaluable if additional buildings or sidings are afterwards required; while, owing to the enhanced value which land in the neighbourhood of stations acquires, it can be re-sold with advantage, if it be not permanently required for the railway.



1.

It is usual in constructing a single-line railway to make certain provisions for converting it into a double line afterwards. Thus land enough for a double line is purchased, the single line being constructed on one side, as indicated above; bridges over the railway are constructed of a sufficient span; the masonry abutments of under-bridges may even be built for the double line, the bridge itself being at first only made for the single line. The cost of rolling-stock depends on the kind and amount of traffic, which have no fixed relation to the length of the line, but from £700 to £1,000 per mile will include the sum which has been found necessary on most of the single lines of standard gauge built in foreign countries.

Efficient narrow-gauge lines.

So much has the standard gauge been associated with railways, that it is difficult for those who have seen no others to realise the efficient services that can be rendered by narrow-gauge lines. It is necessary, however, in considering these to recognise clearly the difference between a railway proper and the subsidiary lines for which a narrow gauge is suitable. For railways very strong reasons are necessary to justify any departure from the standard gauge. Commencing from the very smallest, railways of from 10 in. to 24 in. gauge are sufficient for continuous and heavy services in factories, quarries, and mines, and such lines have the advantage not only of economising cost, but space also, as they can be constructed with sharp curves, and made to branch into places where, without them, it would be impossible to move heavy loads cheaply or even at all. The narrower of such lines should in strictness be called tram-roads, as it is only when a gauge of 18 in. is reached that the use of locomotives becomes profitable or expedient. The smallest gauges on which locomotives work continuously, and with regard to whose efficiency trustworthy experience has been gained, are the railway at the Crewe Locomotive Factory of the London and North-Western Railway; the railways in Woolwich Arsenal, and Chatham Dockyard; and the Festiniog Railway, in North Wales. At Woolwich, Chatham, and Crewe, these small railways merely supplement the lines of standard gauge by which communication with the railways of the kingdom is maintained. The Festiniog Railway, in North Wales, which has been visited by numberless persons desirous of information, is interesting and useful as an example of what may be done under certain conditions; but discrimination is needed in drawing conclusions from its success. The exceptional shape, weight, and uniformity of the loads (slate) which are carried, the solidity of the permanent way, the nature of the cuttings, tunnels, and other works, and the exceptional feature that nine-tenths of the paying loads are taken down-hill, are all circumstances which must be weighed against

Minimum gauge for locomotives.

Examples. *See also page*

Festiniog railway.

the corresponding conditions in any new case which demands consideration.

Narrow gauge lines.

In many foreign countries there is not the same necessity as in England for heavily made wide-gauge railways; or, whatever be the necessity, the want of money precludes their construction. For such cases, light narrow-gauge railways may be adopted with advantage. When the traffic consists only of passengers and of produce or merchandise in light pieces or packages, there is no necessity for the heavy rolling-stock, the heavy locomotives, and the consequent heavy permanent way, nor for the strong under-bridges required by ordinary railways. It is the lightness of the locomotives, and not the mere reduction in gauge, which allows economy in construction, and if there be no risk that heavy locomotives from neighbouring railways will some day come upon the line and injure the permanent way and bridges, the standard gauge, with light rails, light engines, and moderate speeds, may be best. In countries where a low first cost is of importance, and where no great natural obstacles present themselves, the advantages of railway communication can, as already stated, be obtained very cheaply; and in regard to the public convenience, the difference between having no railway at all and having a light railway is immensely greater than the difference between having a light railway and a heavy one. It sometimes happens in a new or half-civilised country that no public spirit or belief in railways can be aroused till one is seen in actual operation; and these also are cases for light lines and cheap first cost. An example of this is afforded by the experimental line constructed in China in 1876, and the Uganda (Africa) railway in 1896. But cheap construction and equipment should not be considered together with large traffic. Such conditions are incompatible.

Light locomotives.

See page 60.

Railways in new countries.

Narrow-gauge railways allow of sharp curves by which the contour lines of hills may be followed; thus in most cases avoiding tunnels, large bridges, and heavy earthworks which, with the standard gauge, would be inevitable. In flat or gently undulating countries, light narrow gauge single-line railways may be constructed very cheaply, as the approximate prices given on page 68 will indicate; and such railways can generally be made to earn a revenue at once.

Advantages of narrow gauge.

If a railway is to be made of a gauge less than the standard, it is always desirable to choose some gauge already in use, so as to utilise

Choice of gauge.

existing patterns in rolling-stock, and to obtain the advantage of experience already acquired as to design and the proper proportion of parts in regard to the equipment of the railway. The narrow gauges tabulated on page 68 are those which for the above—among other—reasons are most likely to be adopted for the future. In the following list are enumerated various gauges which have been adopted in different countries. The first and some others on the list have already been altered to the standard gauge. The list is not an exhaustive one.

List of gauges in different countries.

GAUGE.

ft.	in.	
7	0⅞	Brunel's gauge on the Great Western Railway in England and Wales.
6	0	In the U. S. of America (Erie).
5	6	In Spain, Portugal, Canada, India, Ceylon, Chili, Argent. Repub.
5	3	In Ireland, Brazil, Victoria, S. Australia, Tasmania (Launceston), N. Zealand (Lyttleton).
5	0	In Russia; U. S. of America (Southern States).
4	11½	In Sardinia.
4	9	In the U. S. of America (Pennsylvania).
4	8½	(*Standard Gauge.*) In Great Britain, France, Belgium, Holland, Germany, Austria, Italy, Norway, Denmark, Sweden, Switzerland, British India, Canada, U. S. of America, Peru, Cape of Good Hope, N. S. Wales, Egypt, Mauritius, Java.
4	2	South America (Carrizal Ry. Chili).
4	0	Sweden (Uddevalla), India (Nalhati).
3	9	In Spain (Galdames and Sestao Ry., Bilbao).
3	7⅜	(1·10*m.*) In Belgium (Antwerp-Ghent); Light Railways in Belgium, France and Italy.
3	6	In Norway, Sweden, Spain, Canada, Isle of Man, S. Australia, W. Australia, Queensland, N. Zealand, Cape of Good Hope, Natal, Tasmania, Peru, Chili, Japan, Java, Argentine Republic.
3	3⅜	(*Metre.*) In France, Spain, Brazil, Indian State Rys., S. Indian Ry.
3	0	In England (Ravenglass Ry., Cumberland), Sweden (Palsboda), U. S. of America (Denver and Rio Grande), Guatemala, Mexico (part).
2	6	Wales (Talyllyn Ry.) Southwold, Sweden (Kroppa), Bolivia, China (Experimental Line).
2	6	(0·75*m.*) "Light Railways" in Belgium, France, and Italy.
2	4½	In Hungary (Rostoken-Marksdorf).
2	0	In Venezuela (Bolivar Mineral Ry.).
1	11½	In Wales (Festiniog Ry.).
1	10	In Guinness' Brewery, Dublin.
1	6	In the Locomotive Factory, Crewe, L. & N. W. Ry.; Woolwich Arsenal; Chatham Dockyard.

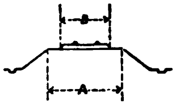
See LIGHT RYS. *page* 77.

Little railways.

The following may be given as the approximate cost of light narrow-gauge railways (single line), including works and rolling-

Ballast.

stock, but not land. A moderate but sufficient amount of ballast is assumed, and more can be added as the traffic demands heavier engines or quicker speed. On English main lines of standard gauge, with heavy trains running at high speeds, ballast 20 in. to 24 in. deep is provided.



2.

For the gauges up to 2 ft. 6 in., an 8-ft. width of formation (A) is assumed; ballast (B) 4 ft. 6 in. wide and 6 in. to 9 in. deep; and embankments and cuttings averaging 18 in. For the gauges above 2 ft. 6 in. a 10-ft. width of formation; ballast 6 ft. wide and 9 in. to 14 in. deep; and embankments and cuttings averaging 2 ft., are assumed.

Cost of narrow railways.

See pages 659 *&* 691. EQUIPMENT & ROLLING-STOCK.

Gauge.		Weight of Engines exclusive of Tender.		Rails and Fastenings.		Cost per Mile.
				Weight per yard of rail.	Weight per mile of single-line Railway.	
ft.	in.	Tons.	Maximum load per Wheel. Tons.	lbs.	Tons.	£ £
2	0	6	1	20	32	1250 to 1500
2	6	9	1½	25	40	1500 to 2000
3	0	12	2	30	50	2000 to 2500
3	3⅜	20	3½	40	65	2500 to 3000
3	6	25	4	50	80	3000 to 3500

There is no fixed proportion between the quantity of land required for a narrow-gauge, and that for a standard-gauge railway. For instance, in the case of cuttings with wide sloping banks, it is obvious that the mere saving in width of formation would bear but a slight proportion to the quantity of surface land, which—whatever the gauge—would be required. Even in a level country, narrow-gauge lines allow only a slight saving in land; the economy of such systems being rather in the easier traction which the lighter rolling-stock requires, and in the sharper curves, and therefore greater choice of route. A narrow-gauge line allows an indirect saving also, because by its sharper curves it may more conveniently be made to follow the boundary lines of property, and so avoid the "severance" which—because of the compensation allowed to the landowners—has proved so expensive in the case of many standard-gauge railways in England.

Severance avoided.

See also page 3.

The cost of construction having been arrived at, there remain, in order to complete the estimate of probable profits, the other points stated on page 58, *i. e.*—

II. *The Expenses of Working and Maintenance.*

III. *The Revenue.*

These may be conveniently taken together, and the proportion which they bear to each other determines of course the amount of net profit which will be available for dividends.

Expenses of working and maintenance.

For the working and maintenance, there are standards by which to measure approximately the probable cost, but these need qualification. In England, for instance, the cost on the principal main trunk lines is from 50 to 60 per cent. of the gross earnings, 56 per cent. being the average of the United Kingdom. But through a given country yielding a certain amount of traffic, a railway 100 miles long may pay well, while a railway only ten miles long in the same district, and with all conditions but length exactly similar, may not even pay working expenses. For on each mile of the shorter line there will be little if any more than the local traffic resulting from the necessities or products of a district ten miles long. But on each mile of the longer line, besides the business of the district immediately surrounding it, there is also the through traffic of the whole 100 miles; the number of stations between which traffic can be exchanged being greater, and the average distance hauled, longer. In other words, the receipts per train-mile will be much larger on the longer than on the shorter railway, while the expense per train-mile ought to be less, because the terminal and other station charges bear a smaller proportion to the total earned; and the expenses of equipment and working will also be less, inasmuch as a less percentage of spare and idle stock is required, the engines and men having their time more completely filled up.

Expenses great on short railways.

Convenient lengths for working.

There are certain convenient lengths of line which allow of economical working. From 50 to 80 miles are such lengths for goods traffic, because a locomotive can work for this distance and back again in one day, and so both engine and men are fully employed. Passenger engines can work from 70 to 120 miles and back again per day, according to speed and other conditions, but if made up of numerous short journeys, a total of from 100 to 120 miles could only be obtained.

Cost of working per train-mile.

It costs a certain definite sum to work a train for a mile; two shillings may be taken as a minimum, and some amount between two and three shillings will embrace the great proportion of all railway working for ordinary trains in England; these sums including all the charges of the railway except that of interest on capital. These limits are, however, exceeded in the cases of heavy express-trains and heavy goods-trains.

Train-mile unit unsatisfactory.

Although the "train-mile" is the unit generally adopted in England for statements of the cost of railway working, it is not a wholly satisfactory unit, because, as the power for working different kinds of trains on different gradients must obviously vary very much, no mere statement of cost per train-mile on different railways will allow a proper comparison, unless the various circumstances are also taken into account. Moreover, the nominal distance run by a locomotive is often increased by the shunting at stations, and the terminal service required, so that on a line with frequent stations, a nominal 50 miles may equal a run of 70 miles on another railway.

See LOCOMOTIVES, *page* 691.

Revenue.

Unless the earnings per train-mile exceed the cost of working, the line manifestly cannot be remunerative, however cheaply it may have been made. Assuming that the line can be maintained and worked for 50 per cent. of the gross earnings (and it is seldom safe to assume such favourable conditions), the revenue which will be required to pay a dividend on a certain capital expenditure becomes a simple matter of calculation. Thus, in order to pay a dividend of 5 per cent. on a railway which is to cost £2,000 per mile, a revenue of £3 17*s*. per mile per week will be necessary; for a railway costing £3,000 per mile, a revenue of £5 15*s*. per mile per week; for a railway costing £6,000 per mile a revenue of £11 10*s*., and so on. Obvious as this may appear, it is unfortunately true that many railways have been constructed without sufficient investigation beforehand into the proportion which the revenue will bear to the cost of construction and working; and however desirable it may be to have a standard-gauge line, with strongly-constructed works and high-class accommodation, the cost must be brought to accord with the revenue, unless there be special reasons to justify a contrary course. Thus the promoters, who may have contributed little to the funds for construction, and whose interest lies in future profits, may be sanguine enough to expect a considerable growth of revenue when the advantages afforded by the railway are developed, and for this reason may be willing to commence with little or no dividend; or the railway may benefit other property in which the promoters are interested, and which may compensate for a small dividend on the capital in the railway. In the latter case, ordinary investors, who

Working expenses. *See page* 69.

Per mile per week.

may have been allured by the example set them by capitalists thus prompted by ulterior motives, will find themselves disappointed. It is in cases where advantages expected to accrue are indirect or prospective, that guarantees become necessary or State railways expedient. But where the receipts do not pay working expenses, even a guaranteed income fails to secure a dividend if some of the guarantee is spent to maintain the working.

Prospective revenue. *See* INDIA, *page* 34. *See page* 33.

The effect of cheap construction on the after working expenses has been already alluded to.

Short lines unremunerative.

A short branch line, on which the working and management charges may be unavoidably high, is hardly ever remunerative *per se*, although as part of a large railway system it may pay, because of the traffic it takes to and receives from the main line. The future prosperity of a new railway will be found to depend very much upon whether it is to form part of a main trunk line, or whether as a spur or branch it will never become more than a local line. In some such cases a break of gauge may be justified, for, as capitalists—presumably—will not provide money for a standard gauge where a sufficient return is impossible, a light narrow-gauge "feeder" line may be constructed, such as are presently described under the head of Light Railways as so common in the continental countries of Europe.

Break of gauge justified.

Feeder-lines. *See page* 76.

Cost of working, how determined.

The nature and amount of the traffic to be carried; the gradients to be overcome; the cost of coal and wages; and a variety of other circumstances, technical and economical, determine the cost of working. The best resolution of the several problems can only be arrived at by considering them together at the outset; but if, as too frequently happens, a railway be made in a certain way simply because other railways have been so made, it may prove unsuitable and therefore unremunerative. It is beside the present purpose, and it would be impossible here, to discuss all these circumstances. It is only here intended to emphasise the axiom that no fixed rule can be laid down for railway enterprise; that it is dangerous to calculate by precedent unless all the circumstances are similar; and that only when possessed of the fullest local information can those who are experienced in such matters advise as to the best methods of attaining success.

Fixed rules fallacious.

Concessions. *See Chaps. II. & III.*

If a railway scheme is brought forward in the nature of a concession, the remarks in the preceding chapters on foreign enterprises generally, will more or less apply; what follows here is of special application to railways. If a contractor be asked to tender for the construction of a foreign railway, he will of course examine the country, either personally or by his agents; and able contractors will be the more willing to incur the trouble and expense of such a survey if the preliminary information supplied to them be full and explicit. If the contractors are to be paid directly in money for their work, they will only have to satisfy themselves that the terms are remunerative, and that those who have to make the stipulated payments may be relied on; and then to direct their attention to the examination of plans and to the local investigation that are necessary to a correct estimate of the cost. But it is sometimes the case that concessionnaires or contractors are required to provide some or all of the capital; or it may be that the payments are to be partly dependent on or secured by the revenue. The contractors will in such cases require special information as to the financial merits of the scheme; as to the data upon which the estimates of future expenses and revenue have been based; and generally as to the points which have been already suggested under the head of concessions. These and various other points may now be summed up and enumerated in the following list; and according to the nature of the case, and the conditions under which the works are to be undertaken, some or all will be found to apply. It will be seen that some of the information required is purely local, and such as can be afforded by any intelligent person who knows the country, while other queries involve technical knowledge and a survey of the route. Sometimes the capitalists and contractors whose aid is sought to construct a railway, prefer to choose the exact route themselves, and to employ their own engineer to make the plans. But even then they will the more readily undertake the expense of a survey if the promoters can furnish them with such local information as may guide them in forming a preliminary and approximate estimate of expenditure and profit.

Capital provided by contractors. *See pages 40 to 56.*

Information necessary. *See pages 19 to 25.*

Particulars classified.

The following list has been made to include the more precise information which must be obtained by those concerned before an actual contract can be made; and it would not be all expected at the outset of an undertaking:—

Map.

1. A general *Map* of the country, showing existing railways, roads, canals, rivers, and the route proposed for the new line.

Utility.

2. The supposed *Utility* of the new railway, and the reasons generally which have suggested its construction.

Powers.

3. The *Legal powers* under which the line is to be built, and the nature of the permission or concession granted.

Plan of railway.

Limits of deviation.
See also page 3.

4. A *Plan* of the line itself, showing, on a larger scale than the general map, the rivers and roads to be crossed, the towns and villages to be passed, and the limits of deviation which the concession allows.

Population.

5. The *Population* of the various places on and adjacent to the railway, and the kind of trade or occupation in which the inhabitants are engaged. The positions of factories and mills near to the line of railway should be indicated on the map.

Traffic and revenue.

6. The nature and amount of *Traffic* anticipated, and the calculations of revenue based thereon. Some assistance in verifying such calculations will be afforded by a description of the means of transport already existing, and the rates paid for freight and passengers. The importance—even to the contractor—of estimating correctly the revenue expected from public works is not always sufficiently appreciated. For instance, where a contractor is to be paid partly in money and partly in obligations, he may deem himself safe, if for the latter portion of his payment he has a first charge on the revenue, which is to be created by an expenditure five or ten times the amount of his claim. But it may happen that the undertaking will only pay its bare working expenses; and evidently no degree of preference will be of value when the net revenue is *nil.*

Width of gauge and strength of works.

See page 58.

7. Information as to the traffic will of course to a large extent determine the width of *Gauge*, the choice of a single or double line, the strength and kind of works, and similar important questions. If a single or double line has been decided on, it should be so stated, and also the width of gauge. If, however, the width of gauge is left an open question, any local reasons for or against a narrow or standard gauge should be stated. The gauge of neighbouring railways, or those to which the new line may some day be joined, will, in conjunction with the information described in the preceding and following clauses, have considerable weight in determining the question.

Sections and gradients.

8. A *Section* of the line on a large scale showing the proposed gradients, the cuttings, embankments, tunnels, and bridges required. If any large or expensive works of this sort are needed, the plan should indicate any alternative routes that are possible, so that the

comparative advantages of various gradients involving greater or less distances, and cheap or expensive works, may be duly weighed, *See page* 3. The preliminary survey and rough sections considered sufficient in the early stages of a proposed new railway scheme in England have been already described.

Geological information. 9. Information as to the nature of the *Soil;* the strata in tunnels and cuttings; and an account of the investigations or the geological evidence on which the facts adduced are based. In the case of *See* GOVT. SURVEYS, *page* 26. tunnels, the sections should be made to show clearly whether intermediate shafts can be sunk, or whether excavation can proceed only from the two extremities. This is important both as regards the time to be occupied in the works, and their cost. The strata above *See* TUNNELS, *pages* 62 *&* 170. the tunnel should be described, and evidence supplied as to the probable presence of water.

See BRIDGES, *page* 133. 10. In the case of large or important *Bridges*, special information should be afforded for estimating approximately the cost.

Building materials. 11. An account of the timber, stone, clay, lime, ballast, and other *Materials* that are to be obtained in the neighbourhood of the railway, and at what cost. The suitability of the timber for bridges, piles, **Timber.** staging, and sleepers is an important point to be noticed, and if railways already exist in the country, the system of permanent-way which has been established or which is deemed best should be described. A description of the horses or other beasts of burden **Horses and forage.** which are obtainable, and their cost, together with that of forage. The kinds of coal or other fuel, and the water, that will be avail- **Coal and water.** able for locomotives; the places where they are to be found, in what quantity, and at what cost.

Transport and Taxes. *See* EXPORT, *page* 442. 12. The facilities for landing and *Transporting* materials that may have to be imported; the dues, import duties, or taxes that may have to be paid.

Climate. 13. The nature of the *Climate*, and its effect upon health; the restrictions which it imposes upon the hours of labour; the destructive effects (if any) it may have upon timber and other materials. Heavy, frequent, or incessant rains; liability to earthquakes, floods, hurricanes, frosts, and snowstorms, also come under this head. Continual or *See page* 691. LOCOMOTIVES. frequent moisture, which would, by making the rails slippery, reduce the adhesion and tractive force of locomotives, is an important incident, especially where there are steep gradients.

Workmen. 14. The kind of *Workmen* that are to be obtained in the country, or in adjacent countries, and whether sub-contractors are to be found who can execute portions of the work. In localities where the wages are low, it is sometimes assumed that works can be very cheaply executed, but as a general rule it will be found that whatever the nominal wages for unskilled labour may be, the real cost, as measured by the work executed, is about the same everywhere.

Cheap labour fallacious.

15. The conditions upon which the *Land* has been or is to be acquired, and whether the railway project is popular or otherwise among the landowners. If the land is to be given gratis, the areas—including surplus lands—should be stated. If the land has to be paid for by the contractors, and if the trouble and expense of expropriation are not to be borne by the promoter, very trustworthy and exact information must be supplied as to the prices; the certainty of obtaining immediate possession; and as to whether, and how far, shares or obligations of the railway will be accepted in payment.

Acquisition of land. *See pages 16 & 26.*

16. The conditions, if any, that have been made by the authorities who grant the concession as to the *Kind of works*, width of gauge, gradients, engines, weight of rails, length of sidings, number and kind of station-buildings, and amount of rolling-stock. It is on these points that differences of opinion often arise. If these matters are not adjusted beforehand by persons of experience, difficulties and disputes are almost sure to occur before the final settlement. It not unfrequently happens that those in a country or district who, perhaps, may have to bear a share of the cost, offer impossible conditions. They require everything of the best, a wide gauge, easy gradients, heavy rails, strongly-constructed works, and perfect equipment, and, at the same time, assume as sufficient a price entirely inadequate. In some such cases, the cost of a neighbouring line is quoted as a precedent, though the conditions may be very different. In other such cases, the preliminary estimate of cost is based upon the report of some official or friendly engineers, who having themselves no risk, look at everything from the brightest possible point of view. A contractor, on the other hand, has to provide against contingencies which he knows from experience are almost sure to occur.

Quality of works and equipment.

Preliminary estimates.

Contingencies.

17. The terms on which *Interchange of traffic* will, or may be, carried on with adjoining railways should be stated, for if left unsettled till the new line be made, a previously existing railway company, having the command of important accommodation, may make terms onerous enough to absorb the profits of the new railway. Where the material and plant for a new railway have to

Interchange of traffic.

Running powers.

Carriage of material.

be carried over existing lines, it is necessary to arrange the rates of carriage.

Terms of payment.
See pages 11, 22, 42, 453.
Retention.
See pages 37 *&* 453.
Amount of retention limited.
See Contract and Purchase, *page* 411.
See page 52.

18. Reference has been made to some different modes of payment. The periods and amounts of the payments are important points for the consideration of contractors. It is usual to retain a certain percentage of the agreed payments until the whole of the works are completed; but where the total amount of the contract is large, and the works will occupy a long time, it is not unusual to limit the retention to a certain sum, beyond which the payments are to be made in full. Where more money is retained than is necessary for this purpose of security, it is really at the expense of the buyer, as the contractor will naturally recoup himself by higher charges for his loss of interest, which will probably be greater than that which will be gained by the buyer who holds back the money.

See Chaps. XXIII.-IV.

The more detailed information which is required for deciding upon the description, and for estimating the cost, of permanent-way and the other equipment of a railway, will be found in later chapters.

Light railways.
Light Railways Act, 1896.
See also Provisional Orders, *p.* 9.

Before leaving the subject of the present chapter, it may be convenient to refer to what are known as Light Railways, which differ in many important ways from those hitherto described. Very few lines have been made in Great Britain which can come under this designation, and the experience gained in regard to them has been mainly in foreign countries. The great need for cheaper intercommunication than the British system allows, and the obtaining of statutory powers by less elaborate methods, induced Parliament to pass the Light Railways Act, 1896, which grants certain facilities. No definition is given by the Act of what constitutes a light railway, but the Board of Trade appears to be the Authority on the subject, and an "Order" confirmed by the Board may be deemed equivalent to an Act of Parliament.

Regulation of Railways Act, 1868.
Limits of weight and speed.
Tramways Act (Ireland), 1881.
Limit of speed.

Previous legislation also serves as a precedent. The Regulation of Railways Act, 1868, contains provisions enabling the Board of Trade to grant licenses for light railways on which no greater load than 8 tons on a pair of wheels shall be imposed, and no greater speed than 25 miles an hour. This did not, however, touch the real question of light railways as described here; the powers were not availed of and had no useful effect. The Tramways (Ireland) Act, 1881, permitted steam tramways to run on the high roads at a speed not exceeding 12 miles an hour, and though these rules if extended to England would have supplied the necessary want, nothing was done till the Light Railways Act of 1896, which points, so far as its intention can be seen, to other methods. The word "railway" has been deemed to mean a line constructed with cuttings, embankments and bridges, and differing from ordinary lines only in the lighter construction and lighter rolling-stock. Powers are given to local authorities to advance money, and also for the Treasury to lend to an extent not exceeding one-fourth of the estimated outlay. Until a wider interpretation is put upon this Act than occurred in the years immediately following the enactment, and an entirely different kind of railed track adopted, the systems so usefully applied in other countries will not be introduced, and it is to these that attention is now directed. By the designation of "light railways" is here meant lines mostly of a gauge narrower than the standard gauge, laid along the high roads and serving for the local traffic.

Government aid. *See page 13.*

Definition of Light Railways.

In most cases these are subordinate lines starting from a station on an ordinary railroad, and frequently also having their other terminus at a railway station or port. It is essential in these subordinate lines that they shall be lighter and cheaper than ordinary railroads; that the ordinary rules of the latter concerning construction and equipment should be relaxed, and that moderate speeds only should be attempted. Tramways are dealt with in another chapter, but the difference between a Railway and a Tramway, though generally evident and well understood, is in some cases very slight and is a mere matter of nomenclature. Tramway is the name given generally to street "rail"-ways, for omnibus traffic and to narrow-gauge lines at mines and public works. Or the name of tramway may be given to any of these lines when they are laid on the high roads, and the name of railway given when laid on a road specially constructed across country with the gradients made as level as possible by cuttings, embankments and bridges. But another essential difference is that between the raised rail, which is best for the movement of flanged wheels, and the grooved rail flush with the surface, which is less convenient for flanged wheels, but which is enforced—as in town streets—where the convenient movement of ordinary vehicles is the first consideration. According to this classification the "Light Railways," which have become common in Europe, may be placed among railways and are so dealt with here, although they are often continuations of town tram-lines.

Light and cheap.

Easy conditions.

Tramways. *See Chap. XIII.*

Laid on high roads.

Raised rails.

Grooved rails laid flush.

Examples. **Objections in Great Britain.**

But, except in the urban portion, they have raised rails, and are generally worked with steam or electric motors. Such lines have proved highly successful in Italy, Holland, France, Belgium and elsewhere, but in Great Britain the objection to raised rails and to the use of locomotives on the public roads has delayed the adoption of this kind of railway.

Excessive cost of ordinary railways. **Cost, how reduced.** **Free use of roads.** **Light track.** **Other savings.** **Rolling-stock.** **Moderate speed.**

The cost of a railroad made in the ordinary manner is often prohibitive even where the needs of the locality demand it, and the main feature which brings the cost within remunerative limits is primarily the free use of the public highways and the omission of special earthworks; additional strips of land being hired or purchased where necessary for passing places. The other economies are in the light permanent-way, which is sufficient for the rolling loads, the absence of fencing, signals—except at or near the terminal stations—and the omission of station buildings, except in large villages, and there only making them of the simplest kind. As the ordinary bridges of the highway are made use of, special structures are seldom required, but both in regard to these and to the gradients the construction of a railway may be made the occasion for levelling off and filling up inequalities where these improvements are equally advantageous to the ordinary traffic as to that of the new line. In return for the special relaxations from ordinary railway rules, the rolling-stock must be within certain limits of weights and size so as not to damage the road and bridges, and the speed confined to a rate of about ten miles per hour, with an occasional latitude up to a maximum of fifteen miles on straight little-frequented roads.

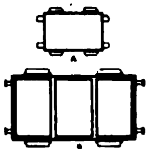
Choice of gauge. **Metre gauge or less.** **Choice, how determined.** **Uniformity with main line undesirable.**

The question of gauge is, of course, a preliminary point of importance. In Italy, some of the lines are of standard gauge; but there, as also in the other countries mentioned, a narrower gauge is adopted, one metre and even 0·75 metre (2 ft. 6 in.) being usual dimensions. Obviously in introducing these light railways for the first time, a standard should be established and uniformity ensured; but, in the choice of gauge, circumstances have to be considered of an entirely different kind to those which determine the choice of ordinary railways. On the latter, the uniformity of the standard gauge is obviously the best; but on light railways constructed on public roads, such a gauge may be an actual disadvantage. It must be borne in mind that light railways are supplementary to and not instead of ordinary lines, and the latter will have to be built when-

Heavy rolling-stock. *See page* 733.

Transhipment.

How facilitated.



3.

Continental methods.

ever the traffic calls for it. Leaving aside engineering questions, the only advantage of uniformity is the use of the same rolling-stock and the avoiding of transhipment. But the ordinary rolling-stock on main lines is necessarily made strong and heavy; it would, if used on subsidiary roads, involve a strength of track and expense which it is desired to avoid; and the wheel-base of such heavy wagons may be unsuitable for the sharp curves of the subsidiary railway. And as the lighter rolling-stock and locomotives which might suffice for the light railway would be quite unsuitable for the main line, transhipment becomes necessary. The cost and trouble are minimised by the use of crates, boxes, cages or baskets of a size having a direct relation to the dimensions of the main-line rolling-stock. Even for such rough goods as bricks, coal, lime or manure, the body of the small wagon may be lifted at the transhipment station on to the main line wagon without any handling of the contents, and two or more of such "bodies" A afford a complete load B. And the smaller baskets or crates used for fish or farm produce can be even more easily dealt with. It is by such convenient arrangement that produce from Holland and France is not only carried cheaply to local markets, but can be brought on the light railway, transhipped to a main line station, thence carried to the export steamer, and on landing conveyed by railway more cheaply than can English produce on English railways, because the various carrying companies are able to handle the foreign packages in a quick uniform manner and on a larger scale than in small lots of different size and shape.

Rules for light railways.

Construction.

Rail-bed.

Rails.

Guard rails. *See page* 302.

The regulations for narrow-gauge light railways differ in the various countries where they have been adopted. The width of road surface abstracted is that occupied by the rails, or from 3 ft. to 5 ft., the track being laid at the side of the road, except in passing through streets, when the track may be laid in the centre. The ordinary macadam being broken up for a width of about 7 ft., a layer of 4 to 6 inches of gravel or ballast is laid, on which the sleepers can be bedded flush with the road. Cross sleepers and flanged rails are universally used, and not the English double-head rail on cast-iron chairs. It is not advisable to have rails weighing less than 35 lb. or 40 lb. the yard. In passing through villages having paved streets, guard rails laid flush with the surface may be used so as to present no obstruction to ordinary vehicles.

Belgian lines.

In Belgium a network of narrow-gauge railways has been established over the whole country, and so distinct are these lines from the main railways that a standard *mètre* gauge has been virtually established for them, although on some of the lines which connect with those in Holland, the Dutch narrow gauge of 1·10 metres has been adopted. The cost of these Belgian railways has ranged from £1,100 to £4,500 per mile, and the working expenses from 50 per cent. to 113 per cent. of the receipts.

Cost per mile.

Traction.

In regard to traction, horses or mules may sometimes be used in countries like Argentina, where the roads are level, fodder cheap, and fuel dear, but in the great majority of cases traction by locomotives is essential to success. Such locomotives may derive their power from steam boilers as on ordinary railways, or may work as oil engines or from electricity generated at stations along the line and conveyed by overhead wires. In France the Decauville locomotive is successfully employed, the whole weight of the engine being available for adhesion without excessive weight on any one axle, and without the rigid wheel-base which would be necessary if coupled wheels were employed.

Locomotives.

Decauville engines.

Capital, how provided.

In Great Britain, and generally also in Europe, ordinary railways have been constructed by private enterprise and capital, though with State sanction and under State restriction. But as the object of light railways of the kind here described is to provide increased facilities for transport in districts where the prospects of profit are uncertain, State aid in some shape is often an essential condition. Such aid, however, is seldom granted except as a supplement to local enterprise, for a community directly interested in the prosperity of a line and directly taxed for it is more likely to abstain from extravagant or non-remunerative projects than where everything is provided from public funds. The absence of such conditions is the main cause why the light railways in France have been financially unsuccessful. In France, State loans were granted so liberally and with such remote terms of repayment, that advantage was taken to make lines profitable rather to the promoters, landowners and contractors, than to the community. There are various combinations possible. In some cases the State, in return for the permanent free carriage of mails and other privileges, will capitalise its payment for such service, and so contribute a portion of the funds. The local community may be able to afford a second portion and be content to stand by and receive interest only after payment of a preferential interest to shareholders or contractors, who are induced to furnish the remaining capital on having the first claim on

State aid. *See page 27.*

Local enterprise.

State loans in France.

Combination.

See pages 30 & 130.

the revenue. In other cases the whole funds may be obtained by loans raised on the credit of the district concerned. In Great Britain it has been unusual to contribute national funds, or even to give any material guarantee to loans for local public works, although the sanction of the legislature to the pledging of local rates has been accepted by investors as an almost equal security, because the raising of rates for the due payment of obligations can be enforced by law. But the great depression of agricultural interests in Great Britain and the amelioration expected from cheapened transport have caused a demand for State aid which may induce a relaxation of the strict rules that have hitherto prevailed, and allow of contributions from the State as permitted by the Light Railways Act.

Local loans in Great Britain. *See pages* 118, 210.

Secured on rates.

Basis for scheme.

In propounding a scheme for light railways, the particulars on which a financial and engineering project may be based differ somewhat from those already enumerated for ordinary railways. Those given for tramways may be considered in conjunction, as well as the following special points :—

Survey.

An exact survey of the roads, giving the width along the route and indicating where additional land will be necessary.

The contours of the existing roads, including the bridge approaches, showing where the gradients may be improved, and occasional cross sections showing the road formation, fences and ditches.

Plans of the villages traversed, showing where stopping and crossing places may be conveniently located and covered sheds erected.

The proposed terminal quays or stations should be fully described. It is desirable to make these alongside the quays or wharfs of existing railways or canals, so as to facilitate an exchange of traffic by transhipment. Facilities for such connections on mutually favourable terms, should be obtained and legally confirmed as an essential part of any new project.

Branch lines.

Where light railways as here described are constructed on the public roads, landowners or occupiers along the route may lay branch lines into the lands they occupy.

[*See also* PARLIAMENTARY PROCEDURE: CONCESSIONS: BRIDGES: TRAMWAYS: RAILWAY EQUIPMENT: ROLLING-STOCK.]

CHAPTER V.

TELEGRAPHS. LAND LINES. UNDERGROUND WIRES. PNEUMATIC TUBES. SUBMARINE CABLES. TELEPHONES.

TELEGRAPHY, or the use of signals for transmitting intelligence from place to place, has existed from ancient times in almost all countries, and the methods employed were brought to a high degree of perfection in England during the long French war which ended at Waterloo. By means of semaphore and shutter telegraphs the Government in London held communication with the principal outports; and, as simple messages could be sent from London to Portsmouth in five minutes, such facilities were, during times of war and threatened invasion, of great value. Such a method of communication was, however, limited to daylight, and was liable to be stopped by fog. Semaphore telegraphs are still used for military purposes, and are useful for signalling across harbours or rivers, or to and from ships at sea. The codes of signals have been improved and simplified, and can be and are arranged so that the same system can be adapted to night-signalling by lanterns or flashes of light. Indeed, the electric telegraph code of Morse is only an application of the same principle; as also are the various military and naval codes by flags, lanterns and light-flashes.

Semaphore telegraphs.

Morse's code.

After the establishment of railways in 1830, the application of electricity to telegraphy—which followed in 1837—formed an important adjunct to the earlier enterprise, though the facilities afforded by the electric telegraph to the safety, management and extension

Electric telegraphs.

of railways have not always been sufficiently appreciated. For some time after 1837 the new telegraphs were confined almost entirely to the lines of railway, and the two undertakings became intimately associated in the public mind. The demand for telegraphs in all parts of the world, and their rapid extension, having necessarily directed the attention of many minds to the subject, continuous and valuable improvements have taken place, the great variety of conditions under which telegraph lines are constructed having taxed to the utmost the ingenuity of those concerned. It would appear as if every possible combination of circumstance and difficulty must have been encountered; but new cases are ever arising which demand new treatment. The improvements that have taken place are mainly in matters of detail; but telegraphs are essentially composed of details, and every fresh experience, however small, has had its value for the future.

Telegraphs associated with railways.

Improvements.

The United States are the only great country where the telegraphs are still owned and controlled by private companies, the transfer of the lines to the Government having been successfully opposed mainly for political reasons. And while in many of the poorer and less advanced countries the telegraphs are still in private hands, there is a tendency towards absorption into the postal service. Only under such management can a uniform tariff be equitably arranged and extensions made into new districts where the traffic would not at first be sufficiently remunerative to capitalists as a separate undertaking. A Government, however, having the security of a permanent monopoly may wisely venture on such extensions for the general good of the community.

Telegraphs in the United States.

Post-office telegraphs.

But although owned and controlled by the government of a country, the construction and equipment are mainly performed by private firms, who therefore look rather to the contractor's profit than to any financial success in the working of the line. There are still, however, also cases where private companies own and manage the lines, and it is to both these that attention is now directed.

Construction of telegraph.

The construction of telegraphs in a new country is an enterprise of a speculative kind, because it offers to the community a convenience rather than a necessity: but in many cases the supply creates the demand. Where one merchant obtains early intelligence, competition obliges all to follow the example: and public opinion leaves the newspaper-press no alternative but to obtain the most recent news. The proprietors of a land line can afford to wait for increased

Telegraph undertakings speculative.

Increase of traffic may be expected.

traffic, because, if properly constructed, the cost of its maintenance is small. Of course, much depends on the proportion which the capital bears to the possible returns. If the mercantile community be small or poor, or the line long or otherwise expensive, a fair return can hardly be expected; for, with small traffic, the rates, to be remunerative, must be high, and the line will be seldom used except in cases of emergency. In cases where the return to be expected is thus doubtful, capitalists will require something more than mere permission to induce them to embark in the enterprise; and assistance or encouragement must be afforded them, in the shape of monopoly, guarantee, subsidy, or otherwise. But whatever be the nature of the assistance thus rendered by the Government of a country, it is, in almost all cases, important for a telegraph company to obtain rights of way for the erection of the poles, and to secure protection of the line by Government decrees.

Concessions.
See Chapters II. and III.
See pages 26–34.
Rights of way.

Where capitalists combine to construct land telegraphs, it is generally through the medium of a joint-stock company, and on the basis of estimates furnished by engineers and contractors who have surveyed the line. The kind of information necessary to such estimates is described farther on. But whatever the particular circumstances, a Government will generally grant to the constructors facilities or immunities of the kind already mentioned for railways; and will themselves take precautions for the protection of the line when finished. As, for the maintenance and working of telegraphs, a special technical knowledge is required, which, though readily acquired under tuition, is not easily procurable in countries where few or no previous telegraphs exist, it is often stipulated, even where the line is to be taken over by the Government, that the contractors shall not only maintain the line in good condition for a certain period, but shall for a short time actually work the line and instruct the officials in their new duties.

See pages 93–95.
Facilities and immunities.
See page 26.
Instruction to operators.

Telegraph contractors in England will not undertake to erect very short lines in distant countries, except at a disproportionately high cost, as there is otherwise nothing to repay them for risks and general expenses which must, even in short lines, be incurred. Cases of this sort come within the category of undertakings which are too small; and such lines should be erected by local contractors, or under the superintendence of local engineers.

Short lines.
See page 50.

In the construction of telegraphs the functions of the electrician are to a large extent absorbed in those of the engineer; and those who devote themselves to such undertakings are classed as Telegraph Engineers. Some of the principal land lines of the world have been laid in the face of almost insuperable obstacles, and pre-eminent among such lines are the Indo-European; the Great Northern of Russia; the line north to south across Australia; the Transandine line from Buenos Ayres to Valparaiso, through the Pampas, and across the snow region of the Andes; and, at a later date, the line from Srinagar in Kashmir to Gilgit.

Telegraph engineers.

Examples of difficult routes.

The construction of the land lines between England and India may be specially cited as conspicuous feats of modern enterprise. The difficulties were so numerous and varied as to demand, besides the skill of the electrician and the resources of the engineer, the perseverance of the explorer and the astuteness of the politician. The physical difficulties were great: deserts had to be crossed, wide rivers spanned, and mountain ranges surmounted. Intense heat in one part of the route rendered work almost unbearable; extreme cold in other districts buried poles and wires for miles in snow: heavy rains rendered insulation almost impossible; while the poles were destroyed by beasts and vermin. The local opposition was of the most aggravating kind; for not only were there avowed enemies who had to be conquered, but mischievous natives who obstructed the work in various ways. When at last, after recourse to punishment, cajolery and bribes, the line was completed, and its maintenance ensured, political or national jealousy of the European servants, and the consequent employment of inert and incapable natives, rendered a regular service impossible.

Indo-European telegraphs.

Special skill required.

Difficulties of climate.

Local opposition.

Thus hindered, messages from England to India, for some time after the completion of the telegraph, took from four to ten days in passing. So successful, however, were the combined efforts of those concerned, and so completely were all difficulties conquered, that the time occupied in the transmission of through messages from London, *viâ* Germany, Russia, Persia, thence by cable through the Indian Ocean to Kurrachee, and by long land lines to Calcutta, was brought down to an average of ninety minutes.

Messages delayed.

Difficulties overcome.

The principal materials employed for land lines are the Poles, the Insulators, and the Wire. In England, wood poles are generally used—larch, Memel fir, and Norway red fir being the sorts best for the purpose. But wooden poles decay, their term of endurance depending upon their quality, on the skill with which they have been

Materials for telegraphs.

Wooden poles.

selected and prepared, and on the climate and soil to which they are exposed.

In England, native larch is occasionally obtainable; but the great bulk of the poles for telegraphs are imported from the Baltic timber countries. The poles selected for this purpose range from 25 ft. to 40 ft. in length; although, for single-wire lines, poles even shorter than 25 ft., and for special purposes long poles of from 50 to 80 ft. and spliced poles of even 90 ft., are sometimes employed. The cost of wooden poles, as delivered from the ship in England, is stated at per lineal foot, the prices ranging from about 3*d.* per foot for poles 25 ft. long and 5 in. diameter at the top, to about 7*d.* per foot for poles 40 ft. long and 6 in. diameter at the top. These prices are equivalent to about 1*s.* 6*d.* per cubic foot, or 75*s.* per load of 50 ft.; and, at this rate, the poles vary in price from 6*s.* to 22*s.* each. One "load" weighs about 1 ton, and measures about 1¼ tons for freight. After the poles arrive in England, and—if for exportation—before they are re-shipped, they are generally creosoted, burnetised, boucherised, or in some analogous way prepared to resist moisture and decay, this treatment adding from 4*d.* to 6*d.* per cubic foot to their cost. Sometimes—especially for native poles in foreign countries where the above chemical processes cannot be applied—the ends which are to be inserted in the ground are merely charred. For countries where native-grown poles are not obtainable, or where, because of climate or destructive insects, wood is useless, iron or steel poles sent from England are generally used: such poles are also preferable, because of their strength to resist hurricanes, and because of the facility they afford for transport in pieces. The poles are made in a variety of ways; sometimes with cast-iron bases and with the upper part of wrought-iron or steel tubes, the choice of design depending on the length of span, the number of wires, the strength of the wind, and the exigencies of transport. Climate, also, and contiguity of the sea, affect cast and wrought iron differently. Great ingenuity is shown in the construction of the poles for convenience of carriage, and for facility of erection. Iron or steel poles vary in weight from 100 to 350 lb. each, but the larger proportion are of some weight between 180 and 250 lb., and it is doubtful economy to employ for a permanent line a pole weighing less than 200 lb. Iron or steel poles within the above limits of weight are about 20 ft. long, and cost from 25*s.* to 40*s.* each. But in countries subject to violent winds or hurricanes, or where wild animals abound,

Cost of wooden poles.

Poles chemically preserved.

Charred ends.

Iron poles.

Division of poles for carriage.

Weight and cost of iron poles.

or where long river spans have to be supported, it is necessary to provide very strong poles, and the iron masts erected in such cases are heavy and expensive.

Number of poles per mile.

Poles are usually placed at intervals of from 60 to 90 yards, twenty to twenty-eight poles being used to the mile, according to circumstances. But when occasion requires, as in the crossing of rivers or ravines, much longer spans are adopted. The Thames at London is crossed at various points by wires of 800 ft. span, while over the wider rivers of the Continent, and over many American rivers, single spans of from 1000 to 2000 ft. are frequently carried. In these cases the conductors used are generally of silicious-bronze wire, which has equal tensile strength, and more than three times the conducting power of the steel wire formerly employed for the purpose. Where more than one conductor has to be carried over such spans, then, in order to avoid the possible contact of separate wires when blown by the wind, or in cities where distinct supports for a large number of wires are not easily obtained, light aerial cables are hung from a suspending wire of steel by strips of raw hide from 3 ft. to 6 ft. apart. The conductors in such cables are of copper wires insulated from each other by coverings of gutta-percha or vulcanised india-rubber; and the required number of these conductors are formed into one cable and covered with tarred hemp. The aerial cables, containing five wires, are about $\frac{3}{8}$ in. diameter, and cables of a diameter greater than $\frac{3}{4}$ in. are seldom used.

Long spans.

Mode of suspension.

Aerial cables.

Insulators.

There is an almost endless variety of Insulators, which are made either of earthenware, porcelain, glass, or ebonite, and sometimes with cast-iron or malleable cast-iron protecting hoods. The choice depends on various practical considerations besides those special to the electrician. Such considerations are the mode of fixing the insulators to the pole and of attaching the wire, the resistance to moisture or decay, facility of transport, and resistance to fracture. The leakage of electricity through the insulators from the line-wire to the earth, which always takes place to a certain extent, becomes in its aggregate sometimes a serious difficulty in the case of a long line and a damp climate; and to prevent this leakage as far as possible, it is necessary to employ the best kinds of insulators and to keep them in perfect condition. On short lines good insulation is of less importance, and therefore less perfect insulators may be used. Ordinary earthenware insulators cost about 1*s.* each; but the better sort of porcelain insulators, with iron hoods, cost from 1*s.* 9*d.*

Leakage.

Cost of insulators.

to 2*s.* 6*d.* each, and weigh from 2 to 3 lb. At intervals—every sixth, eighth, or tenth pole, according to circumstances—straining-insulators are placed, and these weigh and cost about double the simple kind.

Wire.

Diameter of wire.

S.W.G.

See page 552.

Weight per mile.

The Wire almost exclusively used for land lines until about 1885 was of iron, generally galvanised (coated with zinc), but sometimes simply blacked in oil for use in dry climates; in any case the wire was carefully selected of the best quality. The diameter or thickness of wire is stated not only in fractions of an inch (or in millimetres), but by the new Government standard wire gauge, which has superseded the Birmingham wire gauge formerly used. Perhaps, however, a more satisfactory method of denoting the size of wires, and one much used, is by giving the weight of the wire per mile. Iron wire for permanent lines should not be less than No. 8 S.W.G. (= 0·16 *in.* or 4·07 *mm.*, and weighing 356 *lb.* per mile). Stouter wires up to No. 4 S.W.G. (= 0·232 *in.* or 5·9 *mm.*, and weighing 748 *lb.* per mile) is used in the construction of exceptionally strong lines, smaller wires than No. 8 being only employed for temporary lines.

Compound wire.

Hard drawn wire.

Increased conductivity.

Saving in cost.

The cost and inconvenience of transport are in some cases so great that the ingenuity of engineers has been taxed to find a wire which would combine sufficient strength and conducting power with moderate weight. One method adopted was that of using a light steel wire, round which was twisted a riband of copper, the steel and copper being then soldered together and tinned. This, however, was expensive and not altogether satisfactory, so that the discovery of a method of treating copper wire by hard drawing so as to greatly increase its tensile strength (which before was insufficient to allow of its use for overhead lines), has resulted in its almost universal adoption for important telegraph lines, as also for telephones. The advantages of this hard-drawn copper wire are that its conductivity is about six times that of an equal-sized iron wire, so that a copper wire of No. 16 S.W.G. (= 0·064 *in.* or 1·63 *mm.*, and weighing 66 *lb.* per mile) is about equal in conductivity to the No. 8 iron wire; and a copper wire of No. 12½ S.W.G. (= 0·097 *in.*, or 2·36 *mm.*, and 150 *lb.* per mile) is equal to the No. 4 iron wire. By the lightness of the copper wire the strains on the insulators and poles are reduced, and these need not therefore be so large and costly as for iron wires. The reduction in the weight of these materials, as well as in that of the wire itself, allows a saving in first

Corrosion.

Quick transmission.

Cost of copper wire.

cost and in transport which in most cases balances the extra cost of the copper wire. The copper wire also resists the corrosive action of the atmosphere, and therefore costs less for maintenance than iron or steel wire. There is also the electrical advantage that the speed of transmission is greater than in an iron wire of equal conductivity. On very important circuits wires even thicker than those above mentioned are employed, and on lines where the insulation is defective the use of such thick wires will greatly minimise the evils of excessive leakage. When copper is selling at £50 per ton, hard drawn copper wire as above described costs about 7*d.* per lb.

Choice of route.

Great care and judgment are necessary in choosing a route across a new country. Where roads or railways already exist, it is generally advisable to construct the telegraph along or parallel with the same line, thus facilitating the transport of material, and access for inspection and repairs. But it often happens that there are no roads in the required direction, and—the telegraph having to be constructed across country—mountain-ranges, rivers and other difficulties have to be conquered.

Crossing of rivers.

Overhead wires.

Screw-pile masts.

Submerged cables for rivers. *See* CABLES, *page* 102.

For crossing rivers, the alternative advantages of an overhead and of a submerged wire have to be considered. Where the banks are high, and where poles can be erected so that the catenary wire will clear the masts of passing vessels, such a plan may be preferred. The curve or dip of the wire may be assumed as about one-fiftieth of the span. In some cases, where the passage of masted vessels is rare, the wire has even been lowered into the water at such times, so that the vessel may pass over it. There are many rivers which, though wide, have only a narrow navigable channel, and in such cases masts may be inserted in the bed of the river except at the navigable part. So also masts may be erected on the lowlands adjoining a river liable to floods. As, however, struts or stay-wires would, if attached to the masts, be exposed to floating *débris*, the masts must be inserted firmly enough—for instance, as screwed piles—to be independent of side supports. With all precautions, however, great inconvenience and loss have been suffered—particularly in America—from the destruction by hurricanes and floods of the overhead lines crossing wide rivers on masts standing in the stream; and in many such cases submerged cables have been substituted with advantage: the chief risk in regard to such cables being that from ships' anchors and moorings.

Forest clearings. In passing through forests a clearing must be made, or the line in some way be kept clear of falling branches, and this danger is one reason against attaching the wire to growing trees. So also in forests or jungles, creepers which might reach the wire and destroy the insulation, or grass which might ignite and burn the poles, are contingencies to be provided against. **Injury to poles and insulators.** Telegraph poles and wires are exposed to attack not only from wild birds and beasts, but from mankind also. Even in England, boys throw stones at the insulators, while in Persia the natives shoot at them. In cases like these the insulators should be protected by annealed (malleable cast-iron) hoods. Whether from animosity or ignorance, savages or hostile tribes will often damage the line sufficiently to interrupt communication. Sometimes theft is the cause of damage, and the wire and other material are coveted as articles of utility, for though galvanised wire cannot well be smithed, it possesses a value for various purposes, and copper wire, of course, offers a much greater temptation. **Penalties.** Because of these risks, insulators and other parts are in some cases deliberately contrived to be as valueless as possible for any but their proper purpose. Threats and punishment, as well as conciliation, have to be tried to protect the wire, and the engineers who constructed the long lines previously referred to had much curious experience in this respect. In some cases a salutary fear has been inspired by punishing the persons detected in damaging the line, and in others it has been found expedient to permanently protect the line, by granting a small but regular subsidy to the local authorities through whose districts the line passes. **Subsidies for protecting the telegraph.** Superstition—as in China, where the natives say that their aerial gods are offended by the new-fangled structures—jealousy, or pure mischief, will tempt the inhabitants of a country to injure telegraph lines; but when the novelty has worn off, it has generally been found that the line is unmolested. **Superstition.**

The cost of telegraphs. The Cost of land telegraphs depends on many considerations, the nature of which will be gathered from the preceding pages. One of the chief, and at the same time most uncertain, items of expense, consists of the poles, the choice of which is, as has been seen, determined mainly by climate, and the facilities for transport. **Estimates.** Therefore, in estimating the cost of land lines, it will be convenient to consider separately this item. If wooden poles can be procured in the country, their cost can be best ascertained there; but it is not often that the necessary appliances for creosoting the poles are found in foreign countries. The cost of iron or steel poles has been already stated; and if they are required, it remains to be estimated how much it will cost to carry them and lay them along the route, ready for erection. Assuming then that the poles are supplied, and have been deposited along the route free of cost to the contractor, and assuming also that the cost of transporting wire and other material and depositing along the route does not exceed £5 per ton, and that there are no import duties to be paid, then the cost of laying a single-wire line, including simple apparatus and instruments at stations (say one station every ten miles), will be from £20 per mile and upwards. It is only very favourable cases, however, that admit of the above minimum, and such cases are generally those where there is a capable local contractor ready to do the work for a moderate profit. By this means costly superintendence brought from a distance is avoided, and also the intermediary profits of numerous agents, promoters, and contractors. A cost of from £30 to £50 per mile is more usual; and inclusive of poles, but exclusive of buildings, the cost in foreign countries will be generally found somewhere between £40 and £60 per mile. In cases, however, where the difficulties of transport are very great, the cost has sometimes exceeded £100 per mile. The line across Australia cost £160 per mile. If poles strong enough have been erected in the first instance, then the cost of fixing each new wire will be from £3 to £4 per mile, in addition to the cost of the wire and insulators, and of laying these along the line ready for use.

See page 86.

Cheap lines.

Local contractors.

Average cost of land lines.

Additional wires.

Out of Europe, and excluding North America, the total mileage of land telegraph wires in 1893 was about 300,000 miles. The land lines in the United Kingdom had in 1892 about 200,000 miles of wire. In the rest of Europe, in 1893, the mileage of land wires was 1,172,000. In the United States the mileage in 1893 was 870,000, of which the Western Union Telegraph Company alone owned 770,000 miles, which, with their capital of about 25 millions sterling, is equal to £32 per mile; but some of this capital does not represent actual expenditure.

European and American mileage.

Where telegraphs are constructed on a large scale, and where the material employed is chosen for efficiency and permanency, the expenditure is necessarily considerable, and when there have to be added heavy expenses for transport of material, for skilled superintendence brought from a distant country, and finally for

Efficient and permanent lines expensive.

establishment and staff charges, then the total acquires a magnitude apparently out of proportion to that incurred under less onerous conditions. For any but temporary lines, it is always true economy to have the best materials. The cost of transport and the other charges incurred after the material is purchased, bear so high a proportion to the total expense as to reduce greatly even the apparent saving in first cost which the use of inferior materials might allow; while such inferior materials involve the necessity for repairs and renewals, commencing almost from the time the line is opened for service.

Best materials should be used.

Temporary lines.

Land telegraph lines for temporary use only can, under ordinary circumstances, be constructed very cheaply, and, if the exigencies of military service demand it, very quickly also. Much of the expense of ordinary telegraphs arises from the permanent nature of the work. Poles must be strong enough to carry the weight and withstand the strains of heavy wires, and, in many cases, of future additional wires: the poles, if of wood, must be chemically prepared to resist decay, and, whether of iron or wood, must be very firmly fixed in the ground. For temporary telegraph lines, growing trees, light poles, or bamboos, will be sufficient. For permanent lines, strong wire—which will stand constant or repeated heavy strains without elongation or fracture—is necessary; such wire is heavy for transport, and causes great strains on the poles and insulators. For temporary lines, and especially where there is only one wire, more latitude may be allowed, and hard drawn copper wire or silicious-bronze wire (which is even stronger than the copper, but not so good a conductor) of No. 18 or 20 S.W.G. may be used, the supports being as few as 20 to the mile. For permanent lines the choice of insulators is most important; they must be non-conductors, strong against fracture or decay, capable of resisting heavy strains and serviceable for insulation in wet weather. For temporary lines, insulators of a very rude kind may be sufficient, and in some cases may be avoided altogether. In certain conditions of season or climate (dryness is the principal condition), sufficient insulation has been maintained for 100 miles in a wire attached directly to bamboos or wooden poles. For field purposes, wire—insulated in gutta-percha, and fixed on small light canes—is frequently used, thus rendering poles unnecessary. A single copper wire, covered with gutta-percha, costs from £8 to £12 per mile; but, for exposure to the weather, a conductor formed of twisted strands and more effectually enveloped is preferable, and such covered

Light wires.

Cheap insulators.

Field-telegraphs.

conductors cost about £18 per mile. Another kind of light covered wire or cable for military or other purposes, and which has to a large extent superseded the gutta-percha covered wire, is made up of a conductor of twisted strands (these being more flexible than a single wire), insulated with two or more coverings of vulcanised india-rubber, and finally with cotton-tape or braid soaked in some preservative compound such as ozokerite. The conductor in such a cable should be tinned to preserve it from corrosion by the sulphur of the india-rubber. Such cables have an outside diameter of about ¼ in., and cost from £15 to £30 per mile. Sometimes a pair of conducting wires—well insulated from each other—is contained in such a cable, the two conductors being used to form a complete circuit with the instrument, so that recourse need not be had to earth connections. The above class of cables can be rapidly laid on the ground for a few miles from a general's headquarters to advanced posts; the cable is light, supple and elastic enough to suffer the passage of carts or artillery over it without destroying the continuity; and it can be wound upon a reel and used again.

Conductors made of twisted strands.

Cost per mile.

Metallic circuits.

The following information, which can only be obtained by a proper survey, is necessary for enabling an engineer to choose the best route for a land telegraph line, and to advise as to the kinds of material which are most suitable. The route having been chosen, and the materials and other conditions specified by the engineer, the same information enables a contractor to measure the cost of the work, and allows the prospects of success—financial and otherwise—to be estimated by the promoters. In the case of important lines, a contractor, before absolutely concluding a contract, will require to verify—either personally or by his agents—the information and to inspect the route:—

Projection of new lines.

Information necessary.

1. A *Map* of the country, showing the general direction of the line of telegraph and the alternative routes which appear suitable. The towns, villages, roads, railways, rivers, and canals should be indicated on the map, and the places at which it is proposed to have a telegraph station. Existing lines of telegraph in the district should be shown, or any with which the proposed new line can communicate, or which may in any way be in competition with it.

Map showing route.

Junction with existing lines.

2. The miles along the route having been numbered on the map, a written *Description* should be furnished of each mile, embodying the following particulars: the nature of the soil; the facilities, or

Nature of the soil.

otherwise, which it affords for the insertion of poles, and whether the holes can be dug or will have to be blasted; the trees, jungle, grass, or other vegetation, and its character at different seasons of the year.

Vegetation.

Forest clearings.

Mountains.

Crossing of rivers.

3. If forests have to be traversed, the ***Roads*** or tracks which exist should be indicated, their suitability for a telegraph-route described, and the amount of clearing which would be necessary to keep the wire insulated. If mountains or ravines have to be passed, sufficient description, aided by sketches, should be afforded to show any *Difficulties* which may have to be surmounted. In the case of rivers, a section should be given, showing their width, the steepness of the banks, the nature of the river-bed, the depth of water at various seasons and periods of flood, and the direction and strength of the current at these periods. It can then be decided whether the river can be spanned by a suspended wire, whether such a wire would be clear of passing vessels, or whether a submerged wire or cable would be more suitable. In regard to the latter point, the class of vessels, if any, which pass should be described, and the probabilities of risks from anchors.

See CABLES, *page* 99.

Trees or timber for poles.

4. Particulars should be furnished of the trees, canes, or timber suitable for *Telegraph-poles* which exist in the country, together with the locality where they are to be found, the quantity obtainable, the facilities for transport, and the prices.

Climate.

Moisture.

Destructive agencies.

5. The *Climate* should be carefully described, especially with regard to moisture. If no exact register or record has been kept of the rainfall, the seasons of rain, together with the heaviness, frequency, the durations of the rains or dew, should be described as nearly as possible. The occurrence of snow, severe frosts, hoar-frosts, thunder-storms, and hurricanes also must be known; also the effect the climate has upon timber, whether there are destructive insects or vermin, and whether any preservative process for wood can be applied in the country and is likely to be effectual. All the above facts have weight in determining the choice of poles, insulators, and wires, and the methods of attachment. The effect of the climate upon health, so far as it would affect the engineers and workmen who would have to construct and maintain the line, must also be mentioned.

See also page 74.

Beasts and vermin.

6. The *Obstructions*, if any, which are likely to be met with from beasts, birds, the inhabitants, or otherwise during construction.

Population.

7. The *Population* in the districts through which the line would pass; the degree of civilisation they possess; and the restraints, if

any, which it will be necessary and possible to put on them with regard to the protection of the line after its completion.

8. The harbour facilities which exist for the *Landing* of material brought from England; the port or town dues; and the import *Duties* which may be levied. **Harbour facilities.**

9. The means of *Transport* which exist from the port of arrival of the material, or other base of operation to the line of route; and the cost of carriage. The roads for vehicles, or tracks for horses or mules, should be described, together with the facilities for obtaining beasts of burden and forage at all seasons of the year, and at what cost. **Transport.** **Horses and forage.**

10. The kinds of *Workmen*, skilled and unskilled, which are obtainable, and at what cost. The accommodation for lodging the workmen; and the provisions and fuel obtainable along the route. **Workmen.** *See also page 74.*

11. The terms of the permission or *Concession* which have been obtained for the construction of the line. Special information must be afforded as to the right of way over roads and lands for erecting the poles, and the protection against damage to the line when laid which will be afforded by the Government or by the law of the country. **Terms of concession.** *See page 74.* **Legal rights.**

12. The terms of *Payment* which it is proposed to make with the contractor or other constructors of the line. **Terms of payment.** *See pages 25-34.*

13. The *Reasons* which have suggested the construction of the line to the promoters, the necessity or demand which exists for the new line, and the data upon which the calculations of *Revenue* have been based. In connection with these points, particulars should be furnished concerning the number of inhabitants and their avocations in the terminal and intermediate towns, so far as this information will be a guide to the amount and kind of traffic which may be expected. If the promoters desire to provide for a certain amount of traffic present and prospective, sufficient wires must of course be laid and the poles made strong enough for the additional wires afterwards. **Data for calculating revenue.**

14. The terms which have been or can be arranged for the *Exchange* or forwarding of messages by existing lines or cable-routes which the new line is to join. Where the new line is a continuation of, or a branch from, an existing main line, it is most important that access to the capital of a country and to the chief sources of traffic should be obtainable on equitable and remunerative terms arranged beforehand. **Interchange of traffic.**

Damage to overhead lines.

Underground telegraphs.

Early trials unsuccessful.

Berlin-Hamburg-Kiel line.

Conductor cables.

S.W.G.

See page 552.

How made and laid.

Overhead telegraphs as just described are liable to damage during heavy wind or snow, or by the contraction from frost, as either of these events may put such heavy strains upon the wires as to break or force them down. In such a case, not only is communication interrupted, but the road or railroad along which the telegraph runs is blocked against traffic by the fallen poles. These risks have directed the attention of engineers to a more extended use of Underground wires, which, up to 1877, were mainly confined to cities. The Prussian Government laid, during 1847–1852, about four thousand miles of guttapercha-covered underground wires; but these wires were not encased or protected by sheathing, and therefore failed. Underground wires were also laid in England, between London and some of the provincial towns; but at first they were badly constructed, and also failed. A multiple-cable, sheathed with iron, was laid in 1875, between Berlin and Halle; and in 1877 a 7-cored cable was laid between Berlin, Hamburg, and Kiel. Since that date the Imperial German subterranean telegraph network has been completed, some 220 towns having been connected. At the end of 1881, the total length of cables was 5½ million kilometres, most of the cables having 7 wires and the remainder 5 wires. Underground wires in pipes have been made compulsory in New York and other American cities, as substitutes for the poles and overhead wires which disfigure so many of the streets. Difficulties in regard to retardation of speed by induction have to be guarded against; but they can be overcome by proper precautions, which, since 1880, have been generally adopted. As underground wires have not—like those suspended between poles—to withstand heavy strains, the strength of iron is not needed, and suitability as a conductor is alone required; but it is necessary that the wire be protected from damage by digging, from the attacks of vermin and similar contingencies. Light copper conductors of one wire of about No. 18 S.W.G. (= 1·22 *mm.*), or formed of 3, 5, or 7 strands of No. 22 S.W.G. twisted together are generally used; and each of the separate conductors is enveloped in gutta-percha, so as to produce a total outside diameter of about No. 5 S.W.G. (= 5·5 *mm.*). A bundle of such conductors or—as they appear—cords is, for telegraph lines in cities, laid loosely together in an iron trough, or lead pipe, access to which is provided, at intervals of about 100 ft., by openings in the road or pavement, covered with iron doors. The cost of laying underground lines of this kind is in cities greatly enhanced by expenses of paving and by the difficulties of working in crowded streets. From these causes underground lines in London with about 30 wires have cost more than £2000 per mile. For long country lines it is usual to twist the separate conductors into a cable, to sheath them with iron wires, and to coat them with asphalte; a cable thus constructed being effectually protected from vermin and mechanical injuries. The high price of gutta-percha has led, since 1890, to the more extensive use of cables in which the wires are insulated with coatings of vulcanised india-rubber, and of another class of cables in which the wires, coated separately with a loose covering of cotton, are afterwards saturated with some insulating substance obtained from coal tar, the whole being enclosed in a water-tight lead tube. Such cables can be produced very cheaply, and have some electrical advantages over the gutta-percha cables.

City lines expensive.

Underground cables.

How protected.

See also ELECTRIC LIGHT CABLES, *page* 268.

Before leaving the subject of land-telegraphs, the modern systems of subsidiary *Pneumatic tubes* may be referred to. In London and other large cities, where numerous offices for receiving messages are grouped within a moderate distance of the central transmitting office, these tubes have been found very useful for conveying the written messages to the common centre. The tubes are of lead (which has in London been found hitherto to be better than iron), of about 2½ in. internal diameter; and through these tubes cylindrical carriers, or pellets, are blown or sucked by pneumatic pressure or exhaustion. The carriers are of gutta-percha, covered with drugget, and the written messages are placed inside. This plan has been found much cheaper than that of employing messengers or of transmitting the message for the short distance by the electric wire, besides avoiding the risk of errors in the extra transmission. The cost of such tubes, including the laying in the streets, is from £600 to £1000 per mile; the exact sum depending, among other conditions, upon the nature of the pavement. The pumping apparatus costs from £1500 to £2000, and, if placed at the central station, it can be made available for several lines of tubing in different directions. The additional apparatus at each despatching station costs about £100. All these amounts are exclusive of the cost of buildings. In London these tubes are used in all the central districts, and in many of the principal provincial towns. The pneumatic system is also used in Paris, Vienna and Berlin; but, when the practice in these cities is compared with that in London, that of the latter city is found to be

Subsidiary pneumatic tubes.

Convenient for short distances.

Cost of tubes and apparatus.

most expeditious and economical. In connection with the postal service in Berlin there is a complete system of pneumatic tubes for the conveyance of letters from one part of the city to another; letters being transmitted directly they are handed in to a receiving office; the cost to the sender for this service being about three times that of ordinary postage.

Pneumatic system in Berlin.

Instruments.

Batteries, instruments, and the various kinds of apparatus used in connection with electric-telegraphy, are matters of detail, which it is not necessary to treat of here. Out of the great variety of recording instruments which have been invented, only a few of the best types have been permanently adopted and are now in use. Recent invention has been directed towards the acceleration of traffic, and some of the improvements so effected are most ingenious. By the use of copper wire and by improved automatic instruments, six hundred words per minute could be transmitted in 1890, as against eighty words per minute in 1870. By means of automatic "repeaters," messages can be sent forward from one section of wire to another, without the necessity of effecting all from one terminal battery. In England, messages are in this way sent by the one initial operation from London to the extremities of the island. By punching on paper tapes or ribands perforations which represent letters and words, and by reproducing these tapes in sufficient numbers, Press or other long messages can be forwarded from one central office in different directions at once. The air pressure provided for the pneumatic tubes affords power for the punching, and four of the ribands are frequently punched simultaneously, thus augmenting the number of punched messages. Automatic printing instruments record the messages in ordinary type at the rate of about fifty words per minute. Several other improvements in telegraph signalling have been introduced since 1890, and have largely increased the earning power of the lines. Among such improvements the most wonderful is the development of the "duplex" system, by which two messages could be transmitted simultaneously along one wire, either in the same or opposite directions. Out of this grew the quadruplex, and since then the multiplex system, which allows twelve or more circuits to be worked simultaneously over one wire. It is not possible here to give a full description of the methods employed, but taking as an example the system used by the British Post Office, it may be said that by the synchronic movements of two arms, each

Automatic instruments.
Rates of speed.
"Repeaters."
Punched tapes or ribands.
Automatic printing.
Duplex system.
Multiplex system.

Simultaneous messages.

revolving in a circuit of twelve segments at the opposite ends of a conductor wire, and taking a usual speed of three revolutions per second, each segment is excited 180 times per minute, though only on each occasion for $\frac{1}{36}$ part of a second. There being at each end of the line a separate instrument for each segment, the operator has at his disposal what, for signalling purposes, is practically a continuous current, though really it is only at the rapidly repeated intervals as above described, the pulsations being also quite distinct from those at the disposal of eleven other operators, who each control and utilise the pulsations available in the other fractions of each second.

Submarine telegraphs.

Submarine telegraph lines are pre-eminent amongst the modern wonders of the world. The first submerged cable in salt-water was successfully laid from Dover to Calais in 1851, and after three attempts, all more or less failures, in 1857, 1858, and 1865, to cross the Atlantic, submarine telegraph communication between Ireland and America was achieved in 1866, and has since been maintained. When telegraph lines are laid under water, conditions very different from those pertaining to land lines have to be satisfied. The mere insulation and protection from the water could be effected without the elaborate cable-structure which is generally adopted. Thus the submarine line which was laid successfully in 1855, during the Crimean War, between Varna and Balaclava, a distance of 300 miles, consisted of a single copper wire, No. 16 S.W.G. (= 1·62 *mm.*), covered only with gutta-percha, the outside diameter being about $\frac{5}{16}$ in. This cable, though not made in the perfect manner which has since been attained, worked successfully for about nine months.

Cables without sheathing.

Strong cables necessary.

But other exigencies have to be met. Just as the wire of a land line has to be made strong enough to withstand the heavy strains of suspension and of the wind, so has the submarine cable to satisfy conditions also entirely outside those of the electrician. A submarine cable must be made strong enough to sustain its own weight and the other strains to which it is subject while it is being laid or picked up; and it is obvious that the greater the depth of water the greater will be the length, and therefore the weight of the bight. But if the tensile strength be increased by giving more or thicker sheathing-wires, the weight is again increased, and so the two opposing circumstances grow together. The effective weight of a cable is of course less when submerged than when above water, and cables can be constructed with few or light sheathing-wires, which weigh very little

Cables liable to severe strains.

when submerged. The real danger lies in the strains from the vessel from which the cable is being laid or picked up; and even when great care is exercised, it is sometimes impossible, in a rough sea or in a gale of wind, to prevent considerable tension on the cable as it is passing over the stern or when being picked up. Indeed, unless sufficient precaution be taken, the vessel is in effect sometimes anchored to the cable, with consequences that may be anticipated.

Damage from anchors.

Shore ends of cable.

Boring shells.

Submerged cables are subjected also to the risk of damage from ships' anchors, and this risk is of course greatest in shallow waters and much frequented seas; therefore cables which are laid in such situations have to be made much stronger than those for deep ocean service. Thus, while the weight of a deep-sea cable will range from 1½ to 3 tons per mile, a weight of from 4 to 6 tons per mile is considered necessary for such situations as the English Channel: the greater weight being reached when the cable contains more than one conductor. As the cable approaches the shore the danger from anchors is increased. Moreover, the cable is then exposed to the surf, and is liable to be chafed on rocks or shingle; therefore the shore ends of cables are made exceptionally strong, a weight even of from 15 to 20 tons per mile being occasionally attained. In waters where the boring shells (*teredo navalis*) or worms are exceptionally destructive, sheathing-wires are insufficient, and the cable must be enveloped in copper strips if it is to be long preserved.

Improvements in cables.

Certainty of success.

Continual tests necessary.

So many cables have been laid, and so much experience has been gained under what would appear to be every possible combination of circumstances, that all the incidents of manufacture, laying, picking-up, and repairing, are known to those concerned in such enterprises. Consequently, instead of the very great uncertainty which at first existed, telegraph contractors will undertake the laying of a cable, confident that, whatever be the accidents of the operation and the cost, they will finally succeed. But the amount of money invested is so great, and the interests at stake are so momentous, that too much care cannot be exercised in the design and manufacture of the cable in the first instance. Not only must the cable be capable of transmitting messages, but its electric condition must be such as to do so with the greatest speed, so that by taking the maximum number of words it can earn as much as possible. Every material used in its construction has to be carefully selected with regard to the necessary qualities; and the continuity and insulation of the conductor have to be tested through every stage of its manufacture.

Conductor wires.

Each conductor is generally composed of several copper wires twisted together into one strand, instead of one solid wire as in a land line, as by this means is neutralised the effect of fracture in any one wire, which, though of comparatively small consequence in a land line, which can be easily repaired, would be serious in a submarine cable, necessitating in the case of deep-sea cables a costly repairing expedition. In regard to insulation, the manufacture of submarine cables had by 1889 been brought to such perfection, that no immediate improvements were looked for. But the more recent cables of the Atlantic, Indian, Australian, and other lines have in this respect surpassed all that was expected of them.

Insulation.

Description of cable.

Cables differ in their size and exact arrangement, but usually each conductor is enveloped in gutta-percha, somewhat in the same way as are the underground wires previously described on page 88. By the accumulation of very varied experience with submerged cables, great improvements have been made in the details of construction. Not only have the conductors to be electrically insulated, but the materials for this purpose have to be separated by other coatings to prevent certain deleterious chemical action; the inroads of the teredo worm in inland seas have to be prevented (this risk does not arise in deep-sea cables) by a wrapping of brass tape, and then over a coating of tarred yarn the cable is sheathed with steel wires. In order to prevent corrosion, which rapidly destroyed some of the earlier cables, each of the outer wires is coated, and the complete cable finally enveloped in tarred yarn and a bituminous compound. Long distance ocean cables generally contain one conductor, but cables with as many as seven conductors are used in some cases.

Instruments.

The longer the cable, the greater is the resistance it offers to the electric current, and the ordinary ink-recording or needle instruments in use on land-lines are not sensitive enough for signalling through long cables. For the Atlantic cables two kinds of instruments are in use, viz., the "mirror" instrument and the syphon ink-recording instrument. In the former, a small mirror, suspended by a cocoon fibre, is deflected by the current, and the rays of a lamp placed opposite to the mirror are reflected by it on to a scale, the combination of the movements of the bright spot on the scale denoting the letters. The syphon-writer is a very delicate instrument, in which a fine glass tube, acting like a pen, traces the signal on a moving

Mirror and syphon-writer instruments.

Speed of transmission.

Number of words per minute.

Duplicate cables.

paper strip or riband. By these means the effect of the current is utilised to the utmost, and the necessary battery-power kept as low as possible. Although the time actually occupied in transmitting each separate signal is, even in the longest cable, very short, still the signals become less defined and separable as the length increases. To meet this, a greater interval must be left between each signal, and therefore in long cables the number of words per minute is much less than with short lines. The improvements since 1870 have been so great that while at that date 50 words per minute could be transmitted from London to Dublin, 300 words or more could be sent in 1887. On long ocean cables the number is very much less. These circumstances must obviously be taken into consideration when choosing the number of conductors and kind of cable to transmit expected traffic. But although it may prove cheaper to lay one cable with two or more conductor-wires than two cables each with one or few wires, it must also be remembered that a duplicate cable tends largely to ensure a regular revenue, which an accident to a single cable would stop entirely. For long ocean lines more than one conductor renders the cable too heavy.

Methods of laying cables.

Telegraph-ships.

For laying across rivers, bays or estuaries, not much special preparation is necessary. In shallow waters a cable can be best laid by men wading and carrying it from hand to hand: where this is impossible, vessels or large boats can be employed for the purpose. In inland seas a sailing-vessel towed by a steamer can be temporarily equipped as a telegraph-ship, but there is always more risk in such cases than where a proper steamer is used. A towed vessel does not steer well, especially in rough weather, and cannot be stopped quickly in case of fault. Cables have, however, been successfully laid for considerable distances by such means when no proper telegraph-steamer was available. In the case, however, of an ordinary iron steamer used temporarily for such service, the great cost of altering it to make tanks for the cable and for other necessary arrangements is a reason in favour of employing a wooden vessel, which can be altered more cheaply.

Contractors for cable-laying.

Cable-laying machinery.

But although there are contractors and companies who, for a stipulated price, will undertake to make a suitable cable, and to lay it safely, taking all the risk of accident and failure, the price charged for such a service is based upon the very heavy expenses incident to it, and also upon the probabilities of loss as estimated by previous experience. The machinery and equipments of vessels, specially constructed for laying and picking-up deep-sea cables, have been brought to great perfection; and as a result of dearly-bought experience, such vessels and machinery can be employed with a certainty of ultimate success. But although a considerable number of engineers have now acquired experience in the laying of cables, the number of properly-equipped vessels is small, the cost of maintaining them very high, and when in actual work the salaries, wages, and insurance special to the enterprise add enormously to the expenses—never very small—which are always incident to the voyages of steamers. And when a cable has to be laid in a distant sea, the time occupied and the distance from supplies add greatly to the cost of an undertaking, which, as has been shown, is in any case an expensive one. The contractors for such works naturally require in return a high rate of profit. The expenses of a fully-equipped telegraph-steamship, including coal, stores, wages, salaries, insurance, and interest on capital, will range from £5,000 to £8,000 per month, according to the size of the vessel and the exact nature of the service. And to this expense must be added not only the profit of the contractors on the capital embarked in the construction and maintenance of such a vessel, but, if they have undertaken, as is generally the case, the responsibility of laying the cable successfully, an additional sum, which may be considered as a premium of assurance against loss.

Costly steamers.

Expenses during laying of cable.

Apart from the liability to rust, which, as previously described, can be prevented, cables will last for 25 years. Experience like this greatly encourages telegraph enterprise, as it proves that a cable properly made and laid has life long enough to amply repay its cost.

Fluctuations in cost of cables.

The Cost of telegraph-cables, of course, varies according to their size and kind, but it is also subject to fluctuations, not usual in most other manufactures. Although the cost of all articles varies with the value of the materials of which they are composed, it is not often that so many circumstances have to be taken into account as with submarine cables. Copper, hemp, gutta-percha, and iron are the materials used for cables, and the current prices for each of these are determined by causes differing in each case. It may be said, generally, that the cost of cables has diminished, partly because of the skill and experience that have been acquired in all the processes of manufacture, partly because of the fall in the price of copper, and

See COPPER, *page* 369.

Cost of cables per mile.

partly because of the greater competition which now exists. The cost of submarine cables (1896), exclusive of the cost of laying, ranged from £100 to £500 per mile according to weight, as given below.

Cost of single-conductor cable.

Cost of shore ends.

A submarine cable of the most recent kind, with one conductor composed of seven No. 22 gauge copper wires, twisted into one strand, insulated and protected as just described, the cable having an outside diameter of ¾ in., and weighing about 3 tons per nautical mile, would cost from £100 to £120 per mile, according to the prices current at the time for the various materials used. The shore ends and intermediate portions would have conductors and coatings similar to the deep-sea portion, but with sheathing-wires adapted to the nature of the sea-bed, exposure to anchors, and other circumstances; the weight per mile being increased to between 6 tons and 18 tons according to the diameter. The extra price per mile (in addition to that for the deep-sea portion) would be from £25 to £40 per ton of extra weight.

Cost of 3-conductor cable.

A submarine cable with three conductors, each made and insulated in its own coatings, as in the cable just described, would have an outside diameter of from 1¼ to 1½ in., and a weight of from 7 to 10 tons per mile, depending on the sheathing-wires, the strength of which would be determined by the risks to which the cable was to be exposed. The deep-sea portion, which would be used for ocean routes and unexposed seas, would cost from £200 to £300 per mile, while the shore ends and intermediate portion would be heavier and more costly, as described for the single-conductor cable. The average cost of cables as laid throughout the world may be taken at £300 per mile; but losses and initiatory expenses have increased the amount sunk, so that the capital actually spent by the cable companies equals about £350 per mile of cable.

Cable ventures speculative.

For any but a short and easy line, a submarine telegraph is a very speculative undertaking, and one in which, to justify the investment of capital, the compensating revenue must be tolerably certain. Different investors prefer different kinds of ventures, and hence that of making and laying a cable is kept separate from that of the ownership of the cable when laid. The telegraph company which employs the constructors to lay as well as make a cable, have obviously to pay for their services and risks, although they have the satisfaction and protection of knowing beforehand how much they will have to pay. But even where a submarine telegraph has been successfully laid, it is still in an entirely different position from a land line. A land telegraph, if well constructed, need cost but little for maintenance, and the proprietors may be contented with moderate traffic at the commencement if there is a probability of increase; but a submarine line should pay handsomely from the first if it is to satisfy the expectations which alone will justify the investment of capital. Although experience has removed many of the difficulties and risks of repairing and maintaining cables, yet, in order to put such an undertaking on a stable basis, a duplicate line should be laid. It is evident, if the above considerations be true, that a large proportion of the annual revenue—especially when there is only one cable—must be reserved, either for maintenance or as a sinking-fund, before the revenue can justly be applied to dividend. To reduce as far as possible the risks peculiar to such enterprises, special "Trusts" have been formed, by which the capital of investors is divided over several different cable undertakings.

Risks of maintenance.

Sinking-fund.

Cable Trusts.

Submarine cables of moderate length for connecting two parts of the same country, may naturally form part of one general national telegraph system, of which land lines may form the other and perhaps greater part. Where, however, the Government or other owners of the land lines are unable or unwilling to lay a submarine cable, the undertaking affords a legitimate opportunity for private enterprise. In the case of international cables, there are but few instances of the Government of a country doing more than afford permission or encouragement to private capitalists. Assistance or encouragement may be given in any of the various ways previously referred to, or privileges in regard to the connection with existing or contemplated land lines may be granted. In some cases an absolute monopoly has been conceded, which excludes all other cables from being landed; but such a concession, as being against public policy, is rare. The co-operation of numerous capitalists, through the medium of joint-stock companies, is the almost invariable method of conducting these enterprises, which are too speculative to justify large individual outlay.

Private enterprise.

See FACILITIES *and* IMMUNITIES, *page* 26.

See CONCESSIONS, *page* 18.

MONOPOLIES. *See page* 28.

The following information is that which is necessary to enable a telegraph engineer to decide on the most suitable kind of cable; to allow contractors to estimate the cost, and capitalists to calculate how far the enterprise will be remunerative:—

Information on which to base estimates.

1. A *Map*, or chart, showing the places between which the cable is to be laid, and showing any existing cables which must be avoided.

Chart of route.

Depth of water. 2. The *Depth* of water will probably be approximately known from the soundings marked on existing charts; but it is necessary to take special soundings, not only to ascertain the depth of water, but to **Nature of sea-bed.** discover the nature of the sea-bed. Abrupt alterations in depth are to be avoided, as also is a bed of rocks, or boulders. The regular tracks of passing vessels which may approach or intersect the line of the cable, should be indicated, and any other particulars furnished by which the liability to damage from ships' anchors may be estimated. From the information thus obtained, the route which offers the most favourable conditions can be chosen. Such conditions are a level or undulating bed, composed of mud, ooze, or sand.

Landing-places. 3. Places favourable for *Landing* should be surveyed and described. A sheltered bay, a cove, or estuary, with a sandy beach, and out of the way of anchoring vessels, is the sort of place to be chosen. It is desirable to choose such a place, even if not in the direct line, for if an increased length of cable or land line is rendered necessary, the expense will be amply repaid by the safety afforded to the cable.

Suitable seasons. 4. Information should be furnished as to the *Seasons* of the year most favourable for laying the cable, and as to the currents, tides, and winds which usually prevail.

Connections with land lines. 5. The *Land lines* with which communication must be made should be indicated on the map, and the terms on which the transmission of cable-messages and exchange of traffic over such lines will be allowed.

Amount of traffic. 6. The amount of *Traffic* which is to be provided for.

Telephones. *The Telephone* as a means of communication may be deemed the most extraordinary development of the electric telegraph, and as such the British Government claim the monopoly of its use in the United Kingdom for public purposes. But though the control and a first share of the revenue are demanded for the Post Office, the actual working of the telephones, except that of the trunk lines between towns, is left with the companies which established them.

The telephone instrument has been aptly described as a speaking tube capable of almost infinite extension. Just as sound is excited **Sonorous vibrations.** by the action of the vibrations of the atmosphere on the tympanum or drum of the ear, so in the transmitter of a telephone an artificial membrane or diaphragm vibrating as the voice agitates the air in front of it, generates and controls waves of electricity, which passing **Action of telephones.** through an extended metallic conductor and a receiving telephone at the distant station set up similar vibrations in an iron diaphragm, this giving out again in sonorous waves of the atmosphere the speech confided to it.

While the above shortly describes the principle of all telephones the actual apparatus for carrying it out differs considerably in shape and arrangement with different inventors, some forms being more effective than others in intensifying the vibrations of the transmitting and receiving instruments.

Apparatus required.

A complete set of instruments comprises: (1) a transmitting telephone, which is almost invariably of the "microphonic" type; (2) a magneto-electric receiving telephone, preferably of the "double-pole" form; and (3) signalling apparatus. For the latter purpose, except for very short lines, magneto-electric generators have taken the place of the batteries formerly in general use, as being more reliable and effective. A complete set of good instruments as above costs from £3 to £4. One such set being furnished at each end, the arrangement and cost of the line between (if of a single wire) is about the same as for an ordinary electric telegraph, but the material of which the line is made is of even more importance than in the case of the telegraph, iron wires seriously interfering with the distinctness of speech. Hard drawn copper wire should be used for all important lines, but for the short wires in towns silicious-bronze wire of about No. 18 S.W.G. is extensively employed. Underground lines should, as far as possible, be avoided, especially on long lines, as being particularly unfavourable to the transmission of speech, owing to the high electrostatic-capacity of such wires. Many improvements have, however, been effected since 1890 in respect of underground wires, by the use of cables in which the insulating material used for keeping the wires apart has been paper and dry air. These improvements have been stimulated by the action of the municipal authorities, who have in many towns compelled telephone engineers to put their wires underground, because of the alleged unsightliness and danger of overhead lines.

Material of a line.

Improvements in underground cables.

Electrical disturbances.

Owing to the extreme sensitiveness of the receiving telephones to vibratory currents of electricity, which is an essential condition of their effectiveness, the transmission of speech (along single wire lines) is seriously affected by extraneous currents which would not interfere with the working of an ordinary telegraph. Thus where single telephone conductors are carried on poles with other such wires conversation, not intended for that wire, can be overheard, and confusing noises are heard, caused by the currents due to the inductive action of the currents passing through neighbouring conductors, used for telegraph, electric-lighting, electric-traction and other purposes, and at times these noises entirely hinder the use of the telephone. These interferences take place however well the wires may be insulated from each other, and even if they are many feet apart at every point. Other noises are caused by actual leakage of the speaking, ringing and other currents from one line to another, through defective jointing of the wires and from several other causes. To get rid of these annoyances it is necessary to discard the use of the earth connections required with single line circuits, and to complete the circuit by means of a second return wire. In order to ensure complete silence it is also necessary that the two wires constituting such "metallic circuits" shall be so disposed that they shall be equally subjected to the various disturbing causes met with on the route. To attain this object the wires of the "loop" are made to twist about each other in corkscrew fashion. On overhead lines this is accomplished by continually changing the position of the wires on the arms of the poles in a regular manner, so that a complete twist is given to each pair of wires at every fourth pole along the route. Sets of four wires constituting two metallic loops are usually run together on this system, which is called the "twist" system to distinguish it from the "cross" system, in which the wires are not made to twist about each other, but the positions of the wires of a loop circuit on corresponding arms of the poles are changed at regular intervals, so that their average distances from any outside influence is kept the same. Both systems are quite effective when properly carried out, but the latter system enables the faults to which overhead lines are subject to be more easily detected. The twist system has been (1898) exclusively employed by the British Post Office authorities, and the cross system has been most extensively used in America and on the continent of Europe.

Metallic-circuit lines.

Twist system.

Cross system.

Duplex telephony.

Having a metallic circuit line between two points, it is possible to arrange that two independent telephone circuits can be worked by its means—one the ordinary metallic circuit, and the other one a single circuit with an earth return. With two complete metallic circuits it is practicable to arrange four separate circuits, three of which will be metallic circuits, and the fourth an earth return circuit. These arrangements are of importance at times, but the difficulties in the way of maintaining them in good order prevent their being extensively employed. Methods are also in use by which lines,

Quadruplex telephony.

either single or double, may be used for both telephonic and telegraphic purposes at the same time, but owing to similar difficulties to those mentioned above, such arrangements have not been much adopted.

Simultaneous telegraphy and telephony.
See also page 98.

Unlike the case of the electric telegraph, where messages have to be sent to central offices, the telephone instrument is domiciled at the premises of each user, to whom a special conductor has to be set up. Such direct communication is adopted as, from a suburban factory to a town office; between a head office and numerous branches; from a public telegraph office to a house or office; between the signal boxes on railways, and in other obvious ways. The telephone has also completely displaced the A B C telegraph instruments formerly used in branch telegraph offices. The principal use of telephones is, however, in connection with "Telephone Exchanges," which are now established in nearly all civilised towns. From the "central offices" of these exchanges wires radiate in all directions to the premises of those subscribers who agree to pay a certain annual subscription (usually in advance). For this they are supplied with a set of telephone instruments and a line, which the telephone company agree to keep in good working order. At the central office the line wires are all connected to an ingenious arrangement called a "switch-board," by means of which the operators in attendance, on being requested through the telephone by any subscriber, can immediately connect his line to that of any other one, so that the subscribers so connected can converse together just as if they had a private telephone line between their respective premises. The convenience and success of a telephone exchange depends, primarily, on the perfection of the instruments and conductors and their maintenance in proper order, so that the voice sounds can be clearly exchanged; secondly, on the efficiency of the service at the central office, so that at any time of the day or night a subscriber may depend upon a prompt acknowledgment of his call and a connection with the desired subscriber within the shortest possible space of time; thirdly, on the number and distances away of persons with whom he can communicate. Up to a certain, not well-defined, limit, the expense of an exchange can best be borne when there are numerous subscribers; after such point, however, the cost of working increases in a greater proportion than the number of subscribers, so that the subscription rate is in most cases—as, for instance, in London—higher for connection to a large exchange

Use of telephones.

Telephone Exchanges.

Switch-boards.

Essential conditions of success.

Relation of size and cost of working.

than to the smaller ones. This follows from the fact that, as the number of subscribers increases, the greater is the use of the telephone by each one, so that a larger proportion of operators and more expensive apparatus is required to cope with the extra demand for intercommunication. The laying of underground wires, which are fast becoming obligatory in large towns, and provision of metallic circuits, also entail heavy expense in first cost, but if properly carried out ensure good service and a saving in maintenance expenses.

Methods of working exchanges.

There are two main systems of working telephone exchanges:—(1) The "Ringing" system, which is the more usual one, in which a subscriber desirous of calling the attention of the central office, operates his ringing apparatus, causing an electric indicator or drop shutter special to his line to fall at the central office, thus calling the attention of the operator in charge; and (2) the "Call-Wire" system, in which each subscriber, in addition to being provided with an ordinary line (single or double) for use with other subscribers, is also provided with a connection to a "call-wire," which is only used for the special purpose of communicating with an operator at the central office. One such call-wire is common to from 60 to 100 subscribers, and is connected directly to an operator who, during business hours, is continually listening for the instructions of the subscribers, who, by merely depressing a lever on their instrument, can at once get into direct conversation with the listening operator. The switching together of the ordinary lines of the subscribers is done, in both systems, by means of double-ended metallic cords and plugs, which are inserted into sockets numbered to correspond with the subscribers to whom they are allotted, and to whose line they are joined. The call-wire system has been making much progress since 1890, as it possesses several advantages over the ringing system, such as less cost in installation and operators, and quicker operating.

Call-wire system.

Multiple switch-boards.

When a central office reaches more than about 400 subscribers, it is desirable, in order to prevent mistakes and delays in connecting, to provide what is called a "multiple" switch-board, which, by the multiplying and arranging in complete sets of the connecting sockets of one and all the subscribers, enables any one operator, without moving, to connect the lines of any two subscribers, checks being provided to prevent any line being connected to more than one other at the same time. Such multiple switch-boards for large centres are very costly, owing to the considerable number of connecting sockets required (these increasing as the square of the number of subscribers) and the labour involved in fitting up; but on the other hand, such boards save much time and labour in operating, thus giving better service and enabling the work to be done by fewer operators.

Concentration.

In large towns it is advisable, as far as practicable, to concentrate the subscribers' lines into one central office, in order to prevent the delay caused in connecting through other centres, and to retain the advantage of the multiple board; but as the cost of the lines increases with their length, and the subscription rates increase accordingly (beyond a certain limit of one-half or one mile), and may become prohibitive, it is generally advisable to open subsidiary central offices, these being connected to the main exchange by a certain proportion (usually about 25 per cent.) of "junction" lines. The subscribers connected to such centres do not, as a rule, get such good service as those on the main exchange. But even the multiple board, owing to excessive complication and cost, has a limit of usefulness (of about 6000 lines), for which reason, and in order to keep down the lengths of lines, it is found necessary to increase the number of large central offices in very large cities, where a correspondingly large number of subscribers may be expected. In London, for instance, the area worked by the National Telephone Company is comprised in a circle 24 miles diameter, or about 600 square miles. In this area some 30 central offices are established (1895), with about 8000 subscribers, these being arranged in 10 districts, the main centres of these being all joined together by about 2000 junction lines, for the purpose of connecting subscribers in one district to those in another. This switching through junction lines entails loss of time to both operators and subscribers, but this loss is reduced to a minimum by the general use of the call-wire system between the operators of the various districts, such an arrangement greatly facilitating the service on the junction lines.

Junction lines.

Limit to concentration.

London districts.

Call-wire system between exchanges.

Trunk lines.

When the various districts of one city are connected as above described, the ordinary subscription generally covers the whole, but where towns more or less distant are connected by "trunk" lines, an extra fee has generally to be paid for a connection between them. In the United Kingdom the Government charges for speaking over the trunk lines, provided and worked by the Post Office authorities, are as follows: for distances not exceeding 20 miles, 3*d.*; between 20 and 40 miles, 6*d.*; and an extra 6*d.* for every additional 40 miles or under for three minutes' conversation. The National Telephone Company is, however, allowed to make a small additional charge when connections are made to their subscribers. Monthly accounts of such trunk connections are sent by the telephone company to the subscribers concerned, and the company are themselves responsible to the Post Office for the cost of the connections given, a commission of 5 per cent. being allowed them for the trouble of collecting, &c. This arrangement came into force in 1895, the Government taking the trunk line service entirely into their own hands in consequence of the supposed loss which such service (hitherto worked by private companies) imposed on the revenue from telegraph messages. In order to provide good facilities and perfect speaking, the Post Office engineers have constructed a splendid network of trunk lines joining together all the towns of the United Kingdom. From Leeds, as a centre, thick copper metallic-circuit lines, erected on the twist principle, radiate to all the large towns, the wire used for the principal lines being 0·223 inches diameter and weighing about 800 lb. to the mile. As underground lines impair the distinctness of speech, the above trunk lines are placed overhead wherever possible. To connect the towns in Ireland, a submarine cable 24 miles long was necessary. The results obtained are remarkably good, but the cost of such a system of trunk lines is necessarily very high (£1,000,000 has been voted for the purpose), and it is hardly likely they will prove remunerative until the traffic increases. An arrangement has also been made by which subscribers can telephone messages to the central telegraphic offices in the various towns for ordinary telegraphic transmission. The telephone company becomes responsible to the Post Office authorities for the fees for such messages, but are allowed a commission of 5 per cent. for collection. To ensure payment of such fees by the subscribers, the latter are required to deposit with the company a sufficient sum to cover the cost of three months' messages. A similar arrangement is sometimes made to ensure the payment of the ordinary telephone trunk line charges. Messages may also be telephoned to a post office by subscribers for delivery by express messengers, and received telegraphic messages may be telephoned to subscribers. These are all conveniences which the subscribers appreciate.

British Post Office trunk lines.

Privileges to subscribers.

Way-leaves for lines.

In establishing a telephone system in a town or district, the right of way for the conductors is the first essential condition. In the United Kingdom there is seldom much difficulty in obtaining permission from house-owners or occupiers to attach wires or poles to the roofs of buildings. A nominal rental (usually of one shilling per wire per annum) is nearly always paid for such permission. Iron poles are less objectionable on roofs than wooden ones, as requiring less alteration of the building. The noise caused by the vibrations of wires in the wind is often objected to by occupiers of premises to which they are attached, but this may be cured by the use of "Sourdines," of which there are several kinds. If wires are laid under public streets, as is becoming more general, permission from the municipal authorities is necessary, and in some towns such permission is also required for overhead wires. In many towns rent is paid for permission to lay wires in underground conduits built by the corporations.

Municipal regulations

Sometimes a Monopoly for the Telephone Exchange is sought, and this may be granted in various ways, as are other concessions for purposes which involve interference with private rights. In countries where exclusive concessions are the usual means of establishing all enterprises of a public character, a telephone monopoly appears natural; but, in countries where competition is more usual, the only justification for an exclusive concession is the inconvenience to the public of more than one association having the right to lay wires along, across, or under the public streets, and of the subscribers being almost compelled to join the rival systems, unless intercommunication between them is allowed. If the terms of subscription are moderate and the service well performed, there is neither inducement nor necessity for a rival company. A telephone system conflicts to a more or less extent with a telegraph, and where Government or other telegraph monopolies are in existence, special arrangements have to be made for the establishment of the new mode of communication. In Great Britain the adoption and extension of the telephone were delayed and impeded by such conflicts, it being mainly from such impediments (and the lack of competition) that the telephone has not been so generally adopted as in many other countries. In England the working of the telephone has been almost wholly in the hands of one company, which has bought up the licenses of competing rivals. It cannot be doubted that this course has tended to retard the introduction of improvements, and to so inflate the capital of the surviving company as to render high rentals necessary to the earning of adequate dividends. It appears likely, however, that the Government will eventually take over the entire control of the

Concessions and monopolies.
See page 18.

Rival companies.

Competition with telegraphs.

Government purchase.

telephones except for private purposes, such absorption being also probable in most other European countries, in many of which the transfer has already been effected.

Rates of subscription.

The annual subscriptions to the Telephone Exchange vary very much in different countries, being as low as £2 10*s*. in Norwegian towns, and as high as £36 in New York for metallic circuit lines. In Great Britain the subscription in most of the provincial towns is £10, but in London it is £20. The complexities incident to the telephone system produce the curious result that the service, contrary to all other enterprises, becomes more costly to operate as the number of subscribers increases. In London, a subscriber is able to communicate with more persons than in smaller cities; the work of the exchange becomes heavier, and the price paid is larger accordingly. In some places a subscriber pays on what is called the "toll" system, that is, according to the number of times he uses his instrument, a minimum number being charged for. The trouble in this system of checking the calls is, however, considerable, and prevents the advance of this apparently reasonable method.

Toll system of payment.

Capital required.

A capital ranging from £15 to £20 per subscriber is generally found necessary for the establishment of a telephone system, the higher amount being required where large and expensive districts are concerned. The capital required may, however, be materially reduced by charging the subscribers a kind of entrance fee in addition to the usual annual subscription. This plan is adopted in many places on the Continent of Europe, the amount varying from £2 16*s*. in Sweden to £6 in France. In any case it is usual before spending money on an exchange to obtain provisional promises of subscription, and this may be facilitated by granting easier rates or even free trials for a certain period to those who will lead the way. It is endeavoured in some cases to extend the use of the telephone by establishing public call-offices at which any person may for a small fee communicate for a given number of minutes with a subscriber. A facility of this kind, though it may educate the public in the use of the telephone and thus attract subscribers, is seldom in itself a source of profit, and sometimes tends to reduce the number of subscribers by giving facilities which could not otherwise be obtained except by an ordinary subscription.

Inducements to subscribers.

Public call-offices.

Use of telephones in United States.

The United States of America is the country in which the telephone has been most extensively employed, and where the progress has been most rapid. Distances of 1,000 miles and upwards

Long-distance telephones.

are commonly and successfully spoken over. In 1893 there were 276,000 sets of instruments in use; 232,000 subscribers to the 1,351 telephone exchanges, and 441,000 miles of wire in use, of which 91,000 miles were in underground cables. The average number of calls per subscriber per day was over 8, but in Chicago they reached as many as 24·3 per day. In Great Britain 400 miles was the practicable limit up to 1896, with the exception of the line from London to Paris (occasionally connected to Marseilles), but the great improvement in the trunk lines will probably allow a considerable extension of the distance.

[*See also* ELECTRIC LIGHTING: ELECTRIC TRANSMISSION.]

CHAPTER VI.

HARBOURS AND DOCKS. LANDING-PIERS AND JETTIES.

The necessity for harbours.

Natural harbours.

Commerce checked if harbours be wanting.

Bars, rocks, and shoals.

In all countries and districts bounded by the sea, safe harbour accommodation becomes absolutely necessary. Generally, large centres of population, commerce, and manufactures are situated upon the banks of rivers, which serve as ports of entry from the sea, or on the sea-coast itself; and to these centres the great railways and roads naturally converge. In newly settled countries, river improvements and harbour construction should be undertaken simultaneously with the formation of railways; or, at any rate, the internal communications and the openings to the sea should be held in view together, even if the works are not carried out at the same time. Harbours, either practicable by nature, or easily to be rendered so, are unused because the roads or railways inland do not accord; and perhaps when it is attempted to make use of natural advantages, the vested interests of existing, even though inferior harbours whose trade is supposed to be threatened, may prove too strong, and may stifle the new enterprise. Where vessels have to anchor in an exposed roadstead; where the entrance to a river is rendered difficult of ingress and egress by a bar, or where rocks or shoals obstruct a harbour-mouth, the risks incident to such defects have to be paid for either by high rates of insurance, or in the precautions necessary for safety; and the commerce of such a port is greatly weighted in its competition with that favoured by a convenient harbour. A sheltered anchorage, a safe harbour of refuge, or one offering facilities by quays, wharfs, or floating-docks, for quick despatch of cargo, or possessing graving-docks for repairing vessels, will benefit not only the natural trade of the port, but will tend to make the harbour a port of call, and perhaps even make it an entrepôt of an extended trade. The Government or Legislature of a country generally considers it one of their duties to encourage, even if not to undertake, such works; and so important is it that unity of purpose and broad national interests should alone be allowed to prevail, that the promotion of such public works by the granting of concessions to private capitalists, should be permitted only when the above considerations have been allowed to have their proper weight.

Harbour facilities promote trade.

National interests.

In Great Britain, Parliament has authorised from time to time a large expenditure of national funds for harbours or breakwaters useful for the navy, or which may be considered as of national rather than of local importance. The magnificent harbours of Portland, Holyhead, Plymouth, and Dover may be cited as examples. Works of this kind have been carried out in different ways. Sometimes the whole is managed by Government engineers without the employment of a contractor; while in others, contracts are made either for all or—from time to time—for portions of the work. A large amount of harbour and dockyard construction, both in England (as at Chatham and Portland) and at British naval stations abroad (as at Gibraltar and Bermuda), has been performed by convict labour, and provisions for such service are occasionally included even in the agreements with private contractors. The estimated outlay for harbours has often been exceeded; the results have not always been favourable; and there has been a growing disinclination in successive Parliaments to vote money for such works. The more recent harbour works have been in connection with commercial ports, and the expediency of granting State aid to such undertakings has been strongly urged both in and out of Parliament. Such aid has, however, been almost invariably refused, and the tendency has been rather in the direction of permissive legislation, which sanctions the borrowing of money by local authorities, and allows rates or tolls to be imposed for meeting the interest on such loans, and for repaying the principal. Numerous Acts of Parliament of the nature of private Bills have been passed for commercial harbours and docks, and in some instances State aid has been afforded in the shape of advances from the public funds, to be repaid with interest in a term of years. A general Act, intituled the Public Works Loan Act, specially intended for harbour, sanitary

Expenditure for harbours in England.

Convict labour.

Disinclination of Parliament to vote money.

Government aid refused.

Permissive legislation.

Borrowing powers granted.

Private Bills for harbours.

See page 8. PAR. PROCEDURE.

Public Works Loan Act.

and similarly beneficial undertakings, authorises such advances; but the Public Works Loan Commissioners, who—subject to the control of the Government of the day and of Parliament—administer the funds, confine the loans strictly to cases where the harbour works have a more than commercial value; and pecuniary assistance is therefore refused unless the works appear likely, as harbours of refuge or adjuncts of fisheries, to be a national benefit. Even under these conditions advances are made only after reports from Government engineers that the intended works and the estimates of cost are sufficient for the purpose in view, and that enough revenue will be forthcoming to repay the loan. Although for all harbour works of magnitude, authorising Acts of Parliament are necessary, small undertakings, where it is not proposed to acquire land for the purposes of the works, are carried out without the trouble and expense of a special private Act, under Provisional Orders of the Board of Trade already described.

Loan Commissioners.

Loans confined to fishery or refuge harbours.

Reports by Government engineers.

Provisional Orders of Board of Trade. *See also page 9.*

Where the improvement of a harbour, or the construction of a dock, is required for the special interests of a mercantile port, the works may be constructed and paid for by local or municipal capitalists if the expenditure be within their means; but in the majority of instances outside aid has to be sought. In such cases the advantage to the town and to the mercantile community which may be expected to accrue from the proposed works, may be sufficient of themselves to justify the undertaking. But generally it is sought to make the works directly remunerative by subjecting vessels, merchandise, and occasionally also passengers, to a tax or toll for the use of the improved accommodation. So much may the business and prosperity of a town or port depend upon harbour and dock facilities that in the absence of other available capital, a railway company which will benefit by the traffic may provide the necessary funds, and merge the capital outlay into that of its general undertaking. In Great Britain special parliamentary powers are necessary for such action.

Local expenditure for mercantile ports.

Works made remunerative by tolls.

The revenue from harbours and docks is generally levied in the shape of dues on vessels, calculated according to tonnage or draught; on merchandise according to weight, bulk, or value; and on passengers according to number. It is, as has been said, only where the present or expected trade of the port warrants expectations of a revenue sufficient in proportion to the cost to prove directly remunerative as a separate undertaking, apart from the indirect advantages to the town or country, that capitalists will be found willing

Modes of levying tolls.

Capital, how provided.

Joint-stock undertakings and harbour trusts.

Sinking-fund. *See page* 39.

See also page 193. WATER-WORKS.

Dock Companies.

Harbour trusts.

to embark in it without special security. In such case the money may be provided either by share subscription, through the ordinary means of a Joint-Stock Company, or by means of a Harbour Trust. In the former case the net revenue will be applied to the payment of a dividend to shareholders, who, as in the case of joint-stock undertakings generally, will naturally endeavour, by keeping down expenditure and maintaining high rates, to obtain as much profit as possible. In the latter case, the money is raised on bonds bearing a fixed rate of interest, for the payment of which the revenue of the undertaking is pledged, the profits beyond what is necessary for this fixed rate being applied to the extension or improvement of the works, sometimes also to a sinking-fund for the redemption of the bonds, and then to the reduction of the tolls. It will be seen that the joint-stock method is the one most favourable to the speculative investor, while the harbour trust is most conducive to the interests of the port or town. But as, according to the latter system, the stimulus to good management which the self-interest of shareholders affords, is wanting, there is some of the risk which always attends corporate undertakings, of inert or corrupt management. The appointment of capable trustees of high standing, of energetic managers, and the publicity of accounts, are the best safeguards against these risks. The joint-stock companies who own the Docks of London, Southampton, Hull, and Plymouth, afford examples of the one system; and the Clyde Trust, the Mersey Docks and Harbour Board, the Dublin Board, the Belfast Board, the Bombay Port Trust, and the Calcutta Port Trust are examples of the other system. The lower the dues, the more inducement there is to use the port; and sometimes it is so much to the interests of the town or country to attract vessels, that the port is made entirely free, and dues are charged only for services actually rendered in the shape of pilotage and craneage; with sometimes small dues for lighthouses and wharfage accommodation.

Foreign harbour works.

Concessions. *See Chapters II. and III.*

In foreign countries, where there are not the same facilities as in England for obtaining money from private capitalists, the Government has to assist either by subsidies, guarantees, or concessions. A harbour or dock may form the subject of a concession granted to those who will furnish the capital and perform the works; certain rights will then of course be demanded, and the various kinds of engagements under which the works may in this way be undertaken have been already described. The concession may grant either mere permission, or facilities, or subsidy, or monopoly, or guarantee; and the precise terms of such engagements are of course a matter for special arrangement in each particular case. Whatever be the financial conditions on which such works are undertaken, the assistance of a competent engineer is of course necessary, and there are engineers who have made the construction of harbours and docks their especial study.

See pages 27-28.

Harbour engineers.

Natural harbours requiring little alteration.

Some of the finest harbours in the world are those provided by nature, and even where not complete, they in many cases require little alteration to render them commodious and safe. The removing of a few rocks, the dredging of a channel or basin, the extension or alteration of a natural breakwater, the construction of a jetty or quay, may be all that is needed; and such works may often be carried out at a comparatively moderate cost. Even where expensive works will eventually be needed, a moderate outlay in the first instance for protective works may so encourage and extend trade as to provide funds later on. In other cases the works may be of such magnitude, or so difficult, that only contractors with exceptional resources or ability can venture to attempt them. The difficulty of estimating exactly the cost of projected harbour works often renders it impossible to make a satisfactory contract for the whole undertaking, and separate contracts must be made from time to time as the works proceed, or the works must be carried out directly under the supervision of the engineer, without the intervention of contractors. In colonies or distant countries this course is in many cases expedient, even where not absolutely necessary; for where only few contractors are able and willing to tender, and where unknown contingencies have to be provided for, contractors' estimates will often be much higher than the actual expenditure which need be incurred by the superintending engineer.

Difficulty of estimating cost.

Contracts.

Works carried out without contractors.

Contingencies.

As a rule, bays and indentations of coast-line offer the best sites for harbours, and in such cases advantage should be taken of the shelter afforded by natural headlands, to enclose the greatest area of deep water within the works. Provision may sometimes even be made for utilising the quarry space, from which the stone is obtained for forming the sheltering breakwater or pier, by subsequently converting it into a floating basin, as was done in the case of the harbour and dock works constructed at Table Bay, Cape of Good Hope.

Choice of sites for harbours.

Quarry space utilised.

River ports.

Rivers afford the readiest, and on the whole, perhaps, the most satisfactory sites for trade centres; but they have their drawbacks in the shape of swift currents as well as of bars and shoals, which not unfrequently require costly remedial and corrective works, in order to render navigation constantly practicable. The deepening and regulating of rivers, therefore, may be included amongst harbour works. Rivers with wide estuaries flowing through a flat country into the sea, have a diminished velocity as their area extends, and the alluvium, sand, or other solid matter held in suspension is deposited at the bottom of the stream, forming thus deltas, and—by the combination of the tide and seas—bars also, which greatly obstruct the navigation. Examples of this are afforded by the deltas of the Nile, the Thames, Mersey, Danube, Rhone, and Mississippi, and in these cases artificial works of great magnitude are necessary to clear away the obstructions, either directly by dredging, or by removing the cause of them, and preventing their recurrence. Where the mouth of a river appears hopelessly obstructed, artificial canals are sometimes cut to the sea, as on the Nile, and the boat canal on the Rhone. In other cases, such as the Thames, banks or sea-walls are built, to confine the river to a narrow course, thus also reclaiming large tracts of land for tillage; as a third method by building piers at the river's mouth to narrow the channel and accelerate the current, as has been done successfully at Tynemouth; or, again, by the construction of training-walls, dykes or levees (not necessarily higher than the surface of the water), which, by narrowing the real channel, increase the velocity of the current and diminish the deposits. This plan has been carried out with great success at the principal navigable mouth of the Mississippi. The theory by which these operations are justified is to some extent explained by an opposite case, where a river flowing between high banks into the sea retains to the last its velocity of current. Dartmouth Harbour, in Devonshire, affords an example of this kind, the river Dart (which forms the harbour near its mouth) flowing into the sea between steep and rocky shores. The Dart has no bar, although it brings much inland water with alluvium in suspension to the sea.

Remedial works.

Deltas and bars.

Artificial canals.

Banks and sea-walls.
See RECLAMATION, *page* 189.

Dartmouth Harbour.

Marine structures difficult.

There is probably no branch of engineering science which presents so many difficulties as that which deals with marine structures. Difficult, or all but impossible, however, as some proposed harbour works may appear, the facilities afforded by modern science are almost unlimited; and in battling with the winds and waves, there are modern mechanical devices and helps available, of which the following may be specially mentioned as important, viz. Concrete or *Béton;* Dredgers; special Steam and Hydraulic machinery; Diving apparatus; and improved Explosives.

Aids afforded by modern science.

Concrete and béton. *See* PORTLAND CEMENT, *page* 849.

It may be truly said, that the introduction of *Portland Cement,* and of the improved concrete or *béton* which its use affords, have revolutionised the art of marine construction. In the earlier building of harbours and breakwaters, great expense was incurred in the working and carrying of blocks of stone; and very frequently all the efforts of the engineer in this respect were nullified by the destructive force of the waves. Now, the materials for manufacturing concrete are brought easily, expeditiously, and cheaply to the site, and are there either deposited *in situ,* or are formed into huge blocks, which presently become as hard and durable as stone. In the earlier employment of this material by the French engineers, blocks of ten to fifteen tons were deemed large: now, blocks of thirty tons are tossed into the sea by the thousand, and others of all sizes up to, or even beyond, 300 tons in weight are built, conveyed, or deposited wherever they are needed, and homogeneous walls of any length can be constructed. It may almost be said that the power of the waves has in this respect at least been conquered, for although in a few specially exposed situations the heaviest blocks have—as at Wick, in Scotland—been shifted, breakwaters and sea-walls can now be built of a strength and durability never possible before. The engineer to the Dublin Ballast Board successfully constructed the underwater portion of a sea-wall on the river Liffey by means of blocks of concrete and rubble, each weighing 350 tons, which were built on a working floor, and afterwards placed in position with the greatest ease and nicety by a highly ingenious floating shears, which he designed for the purpose. Blocks of concrete, each of 70 tons in weight, were (1876–7) employed to form the foundations of a breakwater at St. Helier's, Jersey; and at the Aberdeen Harbour Works, continuous walls or masses of concrete have been formed *in situ.* Continuous homogeneous walls can be cheaply constructed of concrete, for dock, quay, or other walls, in cases where, if stone or brickwork alone were available, the high cost would forbid the work altogether. Hollow cylinders of concrete have also been substituted with economy for iron cylinders in the foundations of river and wharf walls, on the Clyde, the Thames, and at St. Lucia in the

Large concrete blocks.

Continuous homogeneous walls of concrete.

Concrete cylinders. *See also page* 140.

West Indies. There would appear to be practically no limit to uses for which this comparatively modern material may be successfully employed, where ballast or other substance for concrete is plentiful. Although Portland cement has been in use a sufficient number of years to give certain proofs of its durability, great care is necessary in the choice of the materials for the concrete, in the thoroughness of the mixture, and in the manner of depositing it. For while concrete entirely submerged may remain unchanged, that which is liable to alternate dryness and moisture, and to the percolation of salt water, as by the ebb and flow of the tide, may, under certain circumstances, suffer a chemical change injurious to the binding power of the cement. But with suitable materials properly applied the water cannot percolate, and there need be then no fear for the permanent durability of concrete structures in the sea.

Failure of concrete. *See Chapter XXIX.*

Dredging machinery. *See* DREDGERS, *page* 833.

Improvements in *Dredging* machinery have greatly facilitated harbour work and river improvement. The cost of dredging and of depositing have been so much reduced, that instead of the training-walls and groynes formerly considered necessary for directing the current so as to scour and deepen the river-bed, it is now, in many cases, cheaper to dredge away the banks or deposits which obstruct the tidal flow, and by periodical dredging to maintain a navigable channel. In the majority of cases, the sea is available for depositing the dredged material, which can be conveyed either by steam hopper barges, or in hopper-chambers formed in the dredger itself. The remarkable improvements effected in the rivers Clyde and Tyne are the results of judicious and extensive dredging, combined with the removal of inconvenient bends in the river's course.

Hopper barges.

Hydraulic machinery. *See* TRANSMISSION OF POWER, *page* 403. CRANES, *page* 804.

The modern improvements in *Hydraulic* machinery have nowhere been more successfully employed than in the mechanism of dock gates and cranes, in regard to which there is now hardly any limit of size and weight. For the quick loading and discharging of steamers, steam or hydraulic cranes are indispensable, and experience has shown that to meet the varying positions of the hatch-ways of different steamers, the cranes should be movable, except those intended for only occasional use in lifting very heavy weights.

Cranes for quick despatch of vessels.

Diving operations. *See* DIVING APPARATUS, *page* 841.

The facilities with which *Diving* operations may now be carried on whether by diving bells, air caissons, or cylinders with air-locks, or with the more general diving-dress, admit of the adjustment of work under water, within certain limits of depth, with the greatest nicety. The quay-walls at Antwerp, the foundations of the Forth

Bridge, and the harbour extension works at Dover are notable examples of works carried out by these means.

Breakwaters.

Cost of breakwaters.

The construction of breakwaters below low-water has been much facilitated by these aids, as material can now often be applied with more economy and effect in those situations where formerly vast quantities of stone had to be tipped into the sea, so that the slope of the breakwater might be finally arranged by the waves. The advantages of the "long slope" and the "vertical wall" systems of construction are now better understood, and can be more easily compared, than formerly; but in estimating the cost of projected works, it is very difficult to make a fair comparison with previous undertakings, even of an apparently similar kind. The depth of the water, the frequency of rough weather which may limit the hours of working, and the contiguity of suitable materials for concrete, are among the secondary incidents by which the actual cost is determined. The range of expenditure is very great: in inland or sheltered seas, where the circumstances enumerated above are favourable, sea-walls or breakwaters have been made at rates of from £30 to £100 per lineal foot, while for large breakwaters in exposed situations, such as Portland, Plymouth, Holyhead, Cherbourg, and Dover, an expenditure of from £100 to £350 per lineal foot has been incurred. At the new harbour of Dover, by means of advanced pier work resting on steel piles which support girders and a travelling crane above the reach of the waves, concrete blocks shaped so as to dovetail into each other have been lowered on to the sea-bed by the aid of a large diving bell capable of holding four men. Steam-drills and diamond rock-drills, and the improved *Explosives*, dynamite and gelatine, all act as aids to the accomplishment at moderate cost of subaqueous operations.

Advanced pier work of steel.

Rock drills.
See also page 816 · **Explosives.**

New difficulties.

New machinery devised.

But with all the aid afforded by these modern inventions, the ingenuity of engineers and contractors is taxed to the utmost to devise means of overcoming new difficulties. Unlike railway and similar works, it is almost always necessary in sea work to devise special tools or plant, adapted to meet the exigencies of each particular case. Temporary staging may be needed, and yet staging, owing to the force of the waves, or the nature of the sea-bed, may appear impossible. Dredging may be necessary, apparently of insurmountable difficulty; weights may have to be lifted beyond the power of any existing crane. Perhaps, nowhere is the application of mechanical contrivance to constructional work better exemplified than in the special cranes, or setting-machines, used in harbour works, where, with an overhanging arm of eighty feet, blocks of fifty tons are deposited anywhere within an all-round traverse. By means of an overhanging crane (sometimes called a "Titan") the breakwater at Kurrachee was advanced 700 feet in less than four months; and the same appliances were afterwards used at the Madras harbour works. At Colombo, Ceylon, 950 ft. of breakwater, consisting mainly of 33-ton concrete blocks, were set in six months during the favourable or north-east monsoon.

Concrete setting machines.

Cranes. *See pages* 116 & 809.

The construction of Docks may be considered as subsidiary to the greater works of harbours, but the increasing shipping trade of the world is rendering them in most countries hardly less necessary for the purposes of international commerce. In countries like those bordering on the Mediterranean, where there is little or no tide, basins and quays open to the sea may alone be necessary, but in those countries where the rise and fall of tide are considerable, docks with systems of locks and gates are needed. On tidal seas or rivers the level of the water in the dock is generally that of ordinary high tide, and in the case of docks situated on muddy rivers such as the Thames, the Humber, and the Severn estuary, considerable expense is incurred in periodical dredging to maintain a proper depth. On tidal rivers, where there is an ample supply of land water to replenish the dock it may be best to maintain the level in the dock at a higher level than the highest tide, and to let vessels in and out by locks. By this means an inward flow of water which would deposit mud is avoided, and the outward flow flushes or scours the dock. In the case of rivers where the lift of tide is not great, vessels may be accommodated alongside the river walls, as at Glasgow, Newcastle, Belfast, Dublin, and Melbourne, the necessity for dock works not being felt until the shipping traffic has increased beyond what the river frontage can receive. In England the docks of London, Liverpool, Hull, Grimsby, Cardiff, Newport, Leith, and other of the principal ports, afford examples of engineering enterprise and skill, carried out by private capitalists, second only in extent and value to railways.

Docks.

Mud deposit.

Dredging.

Scouring.

Examples of modern docks.

The following information, *inter alia*, is necessary to the design of harbour works, and it will be seen that the particulars described are mostly matters of fact, which can be ascertained by local engineers or surveyors. On the basis of such information the salient points of

Information necessary.

a design will probably present themselves at once to the engineer, and if not able without more inquiry to propound a complete scheme, he can generally give useful preliminary suggestions as to method and cost; and will be able to select at once, with a view to a complete elaboration of his ideas, those out of a multitude of facts which demand fuller investigation and inquiry.

Particulars classified.

The information required is as follows:—

Charts and soundings.

1. A *Survey or chart* of the coast at and near the site of the proposed harbour or docks, including a complete set of soundings.

Tides.

Nature of sea-bed.

2. The maximum rise and fall of *Tides;* the nature of the sea-bed as ascertained by borings, with any corroborative information obtainable as to strata near the shore; the suitability of the bed for dredging, pile-driving, building, and anchorage. As the character of the proposed works may be determined from this information, the above particulars cannot be too full or precise.

Quicksands and currents.

3. The existence of any *Quicksands*, travelling shingle, or sand in suspension, and the direction of the tidal or river currents should be noted; and the movements which have taken place in preceding years should be described, as well as any advance or recession of the sea line.

Winds and seasons.

Information from pilots.

4. The prevailing *Winds* and the lines of greatest exposure should be described, as well as the nature and effect of hurricanes which have been known to occur, and (in the case of a bay or gulf) the length of "fetch" from head to head, or point to point. The winds, seasons, or tides most favourable to entering or leaving the river, or existing harbour, and the reasons which may have suggested new harbour works. The proportion of fine to rough weather which is usual in the year, so far as it may determine the number of working days for sub-aqueous operations. Information, such as can be obtained from local pilots, as to vessels making and leaving the harbour or coast. The distance to which it is desirable that harbour lights or beacons should be visible.

Draught of vessels.

5. The build, tonnage, and *Draught of vessels*, which are to be accommodated in the harbour; the harbour facilities already existing; the manner adopted for landing goods.

Map of town and approaches.

6. A *Map of the town* or buildings which exist, or are to be built near the harbour, with the levels of such roads, railways, rivers, or canals as would have to be considered in arranging the landward approaches to the harbour.

Obstructions to foundations.

7. The presence of *Rocks*, boulders, old foundations, or other

obstructions to piles or stonework, should be indicated and described. The kind of vehicles which will come upon the quays or piers, with the amount of their loads, and, if railway lines are intended, the weight and size of the engines and rolling stock. The descriptions of goods which will have to be landed or shipped, so far as this may affect the number and kind of cranes or other machinery.

Traffic on quays.
See LOADS ON BRIDGES, *page* 148; CRANES, *page* 794.

8. The system of *Dredging*, if any, which may have been used in the locality, and with what success; and the distance to which dredged material must be taken to the sea or estuary.

Systems of dredging.
See page 833.

9. If docks are intended, deep and accurate *Borings* should be made to ascertain the nature of the strata, and the presence of springs or streams which may interfere with excavation or building operations. Also whether the river or other land-water above the level of the tide may be depended on to supply the dock independently of water from outside. The maximum size of the vessels which will enter; the depth over the dock-cill which it is desirable to attain, and also the amount of quay space required.

Information for docks.

See page 125.

Depth of water and quay space.

10. The existing facilities for *Landing* materials, plant or machinery, such as may be needed for the new harbour works.

Landing facilities.
See page 74.

11. Local information as to *Climate*, building materials, and labour, such as has been already described, so far as they would apply to new harbour works. Special information as to the kind of stone and hydraulic lime or cement most easily procurable, either as suitable for face-work, rubble, or concrete; the existence or otherwise of ballast or clean shingle and sand for concrete; the kind of timber obtainable in the country suitable for piles and staging; with information as to the effect of marine worms, white ants, climate, or other destructive agencies upon different kinds of timber.

Climate.

Building materials and labour.
See page 74.

Marine worms.

12. The *Conditions* under which the new works are to be constructed, the terms of the concession, the methods intended of raising capital and applying revenue, and, generally, information on this point already referred to.

See CONCESSIONS, *Chapters II. & III.*

The construction of a *Pier* for landing goods or passengers is an undertaking somewhat akin to that just described of making a harbour, and the pier often forms part of the larger enterprise. It sometimes happens, however, that a harbour is not needed or cannot be afforded, and a pier alone is constructed. Where the water shallows very gradually to the shore, and where no accommodation

Landing-piers.

exists for bringing vessels alongside a quay, the inconvenience is very great, for ships have then to anchor some distance from the land; goods have to be brought ashore in lighters, and passengers landed in boats. The prosperity of a province or district or town may depend upon facilities for shipping merchandise and—though generally in a less degree—on facilities for landing. Especially in regard to minerals, mines—otherwise valuable—may be commercially unworkable without access to export vessels. In such a case when a pier gives life to a trade otherwise impossible, those who embark capital in its construction may legitimately require a liberal and preferential return.

See page 353.

Modern facilities for pier-construction.

The construction of landing piers has been facilitated by the various modern improvements in sub-aqueous foundations. Those specially applicable are screw-piles and cylinder supports, which are more fully described in another chapter. Screw-piles will penetrate almost every kind of stratum except rock, and when properly inserted and braced are very stable; they do not occupy much space in proportion to their strength, and their rounded surfaces offer but slight resistance to the waves. Accumulated experience in regard to marine structures has taught engineers that it is easier to avoid the force of the waves than to resist them. Except, therefore, in those cases where a breakwater is required, a landing-pier is best made of open framework. Everything hollow or angular in the structure, which affords a hold to the waves, should be avoided as far as possible, for the mere difference between an angle bar and a round bar is in this respect very great. Groups of piles or columns, if properly braced together, have enormous strength to support a load, and at the same time present but little surface to the waves; and if suitably strutted and protected by fender-piles, such structures will resist also the rolling of vessels due to any but the roughest weather. All horizontal landings or staircases which, as in tidal structures, will be reached by the sea, should have openings to let the waves pass through, and the deck or platform of the jetty must be so high as never to be beaten by waves from below, or it will be liable to destruction.

Screw-piles and cylinders. *See page* 139.

Resistance to the waves to be avoided.

Landings and staircases.

Pier-heads.

The pier-head is generally widened out, and, because more exposed, the supports are closer and more strongly braced than in the other part of the structure. In situations exposed to heavy winds or rough seas, the pier-head should be so designed that vessels can be moored in a position to leeward of the weather, whatever be the direction of the wind or tide. The principal risk is from the collision of vessels.

As in the great majority of cases the spans of a landing-pier are of moderate size and the loads not excessive, the individual supports are not required to be of great strength; so that columns and screw-piles of small diameter are used more frequently than in bridges. For piers, however, at which vessels are loaded and discharged; on which strong cranes have to be fixed, or railway waggons and locomotives carried; and especially when it is also desirable to have the supports few and far between, large cylinders, columns, or groups of piles are used for the foundations in the same way as is necessary for bridges. But while the steel work of a pier resembles very much in kind and cost that of a bridge, the erection on the site is often more troublesome and expensive. The staging, rafts, or boats, which can be used without difficulty in the construction of river foundations, are in the sea often exposed to violence from the winds and waves, and during stormy weather to collisions. Special precautions become necessary for the protection of the structure during progress, and, despite these, the work is often altogether stopped in stormy seasons.

Piers and bridges compared.

Risks during erection.

Where a pier is constructed for the purely utilitarian purposes of landing and embarking passengers and goods, the undertaking is—so far as the investment of capital is concerned—in the same category as harbours, and the capital can be raised and a revenue obtained in the same way. There is, however, the important difference that a landing-pier is generally a much smaller undertaking than a harbour, and is therefore more within the means of local capitalists or of private joint-stock companies.

Pier Companies.

Where it is required that a pier shall act as a mole, or sea-wall or Breakwater, a much stronger structure is required, and if an iron framework is still preferred, heavy stone or concrete work should be placed behind and between the ironwork, to which, if necessary, a smooth surface of iron plates can be attached to take the first shock of the waves. But generally, where a solid pier is wanted, it is built entirely of masonry or concrete blocks, though even in this case screw and other piles are very useful as an advance work or staging, from which the more permanent structure can be built as at Dover. The unwillingness of English manufacturers to erect bridges abroad applies equally to landing-piers.

Breakwaters.

See pages 50 *&* 136.

During the fifty years ending 1897 a great number of promenade

Promenade piers.

Cost of maintenance low.

Capital provided in locality.

piers have been constructed on the English coasts, generally at some cost between £5000 and £30,000, and they have in the majority of cases proved highly remunerative, although, partly by the desire for cheapness, and partly through want of skill in their design, many of such piers are not sufficiently strong to withstand the heavy storms which may periodically be expected, and there have been numerous failures, some of them disastrous. Having been constructed with only a slight margin of safety, insufficient attention to inspection and repairs has rendered them unable to bear a maximum load or stress of weather. At a watering-place, where the visitors have much leisure time, a pier is sure to be welcomed, and, if well situated, generally proves the favourite place for redezvous and promenade. A pier, once properly constructed, does not cost much for maintenance if a system of inspection and renovation be established from the commencement, and even a small revenue will go far in paying interest on capital. Where a promenade pier is proposed for a town already well frequented, and where a remunerative revenue may be expected from the commencement, capitalists may be willing to provide the means for building it; but where the pier is wanted to aid in the development of a seaside resort with only a small population, then the landholders and householders in the town and vicinity must provide a considerable portion of the funds. And as these locally interested persons will have the indirect advantages of the undertaking, they must be content to allow the outside capitalists who may join them a preferential interest. For instance, if two-thirds of the capital be provided in the district benefited, a contractor-capitalist may be willing to furnish the remainder if he has as security debentures with a first charge on the revenue.

Information necessary.

Particulars classified.

To enable an engineer to make a suitable design for a landing-pier, and a contractor to estimate the cost, it is absolutely necessary that sufficient information of the kind enumerated in the following list be furnished. The expense incurred in obtaining these preliminary particulars will be amply repaid, for unless based on actual facts, any so-called estimate of cost is fallacious.

Plan of site and approaches.

1. A *Plan* of the site, showing the coast-line, the position proposed for the jetty, its length and width, and the land approaches.

Section showing levels.

2. A *Section* of the shore and sea-bed along the line of the proposed jetty. This section should show the levels of the road,

quay, or other approaches, the slope of the sea-bed, with the soundings and tide levels of the water at all seasons.

Sea-bed strata described.

3. The *Sea-bed* must be described (trial borings being made, if necessary), the section thus indicating the clay, sand, mud, shingle, chalk, rock, or other material of which the sea-bed is composed. It is obvious that only by a correct knowledge of the strata, from the surface down to a firm foundation, can the engineer decide the kind, shape, and number of the screw-piles or other supports, and a contractor estimate the cost of fixing them.

The intended purpose of the pier.

4. The *Purpose* for which the jetty is intended. If vessels are to lie alongside, their tonnage and draught should be stated; and it must be known also whether the vessels will be so exposed to the wind or the waves as to cause them to roll against the jetty.

Currents and winds.

5. The direction of the *Currents* and the prevailing winds should be stated, as information on these points may determine the positions for vessels to lie alongside. The liability, if any, to storms; their force and effect; and the seasons at which they generally occur. If passengers are to land and embark at the jetty, information should be furnished as to the kind of vessels or boats which will come alongside, or such particulars as will indicate what staircases and landings will be required at different levels. The pier-head can be arranged to afford these accessories.

Landings and staircases.

Cranes for landing merchandise. *See* CRANES, *page* 791.

6. If goods are to be landed, *Cranes* have generally to be provided; and it is necessary to know where these are to be placed, and the maximum weight they will be required to lift. If fixed cranes are used, the jetty can be made specially strong at these points; while, if the cranes are to be movable, the platform must be designed accordingly. An independent timber landing stage is sometimes built beyond the steel structure.

The loads to be imposed. *See* BRIDGES, *page* 148.

7. If goods are to lie on the jetty, a maximum *Weight* or load per square foot of surface must be stated, for which provision must be made in deciding on the strength of the structure. The carts or other vehicles which may come on to the jetty should be described, and their weight when loaded given. If a railway is intended, the number of lines, width of gauge, mode of traction, and weight of locomotives or electric cars should be stated.

Sheds and beacons. *See* IRON HOUSES. *Chapter XXX.*

8. If sheds or *Buildings*, beacon or lighthouse, are required on the jetty, their size and purpose should be described. Pavilions are

frequently erected on the pier-head; sometimes with a band-stand on an upper story, which together may add considerably to the loading.

Landing facilities, building materials and labour. *See page 74.*

9. Information of the kind already described should be furnished concerning the facilities for *Landing* materials, of dues or taxes, the cost of material and labour. Particulars of the timber obtainable in the country—its suitability for piles, staging, and decking, and its cost—are especially necessary. It is convenient to know if illuminating gas or electric light is available or required.

Terms of concessions. *See Chapters II. and III.*

10. If assistance in furnishing capital is invited, the *Terms* of the concession, and the data on which revenue or profit has been calculated, should be very fully stated.

[*See also* CONCESSIONS: BRIDGES: RECLAMATION: CRANES: DREDGERS: DIVING APPARATUS: PILE-DRIVERS: ROCK-DRILLS: PORTLAND CEMENT: IRON HOUSES.]

CHAPTER VII.

BRIDGES. SUBAQUEOUS TUNNELS.

HIGHWAY bridges are generally constructed as public works, but in poor or newly-settled countries, the demand for new bridges often exceeds what the public revenues can afford, and the traffic has to cross unbridged rivers by ferries or fords. The necessary accommodation is, however, sometimes obtainable through the action of private capitalists, to whom, until free bridges can be afforded, permission is granted to construct toll bridges. As the population increases, or new districts are opened out, the necessity for more bridges is continually arising; the inconvenience being felt most seriously in those districts—of which America and several of the British Colonies afford numerous examples—where the rivers are subject to floods which make them at times impassable by ford or ferry. Subaqueous tunnels may even have to be considered.

Bridges constructed as public works.

Toll bridges.

Want of bridges in new countries.

Subaqueous Tunnels.
See page 170.

Wherever the risks and expenses of construction are great, and the chances of a remunerative return doubtful, the granting of privileges to those who will promote or undertake the construction of a bridge is justifiable and expedient in the interests of the community. For not only may the construction of a much-needed bridge be thus assured, but the bridge proprietors will be content with a less revenue, and therefore a more moderate tariff of tolls, than if they were to be exposed to the risks of competition in the event of their venture proving successful. Moreover, in granting privileges, the authorities may reasonably demand an efficient service in return. Bridges are frequently unfitted for heavy loads, and the proprietors, desiring a

Privileges granted.
See page 27.

Moderate tolls prescribed.

Efficient service demanded.

bridge sufficient only for ordinary traffic, might be unwilling to incur extra expense in providing for exceptionally heavy loads, which will add but slightly to their revenue. But it is of great importance that the passage of machinery, or other heavy merchandise, should not be impeded; and the load-carrying capacity of a proposed new bridge should be clearly specified to accord with all probable demands upon it. A concession for a bridge generally has, wholly or partially, the character of a monopoly, and it is seldom that capitalists will be found willing to invest their money in such a venture except with this condition. Occasionally, however—as in cities—notwithstanding the contiguity of other and even free bridges, the new structure may be of such convenience as to obtain a remunerative traffic. Sometimes the mere possession of a favourable site gives sufficient advantage over any possible competition. The site may be favourable in the sense of its allowing a cheaper bridge to be built than elsewhere in the vicinity, or because main roads converge to it, bringing traffic that could not go so well elsewhere. An absolute monopoly for a certain distance above and below the proposed new bridge is of course preferred by capitalists; the distance depending on the amount of traffic which the district is likely to afford. Sometimes, however, the concessionnaires stipulate only that, until their toll bridge has been purchased from them on terms which may be agreed, no public or free bridge shall be erected within the prescribed limits; and, the first bridge having possession of the approaches and perhaps other advantages, the risk of future competition is considered sufficiently remote. Additional value is given to a concession when it is accompanied by facilities or immunities which cheapen the cost of construction or maintenance. A Government subsidy may be granted towards the cost of the bridge, or contributions towards the capital may be made by landowners or others who are to be benefited, such contributions taking the most effective shape when the interest on them is made secondary to a preferential interest on the capital of the concessionnaires who find the larger share, or who have the risks and responsibilities of building the bridge. Even where no direct contribution is made to the cost, the raising of capital for a toll-bridge may be facilitated by a guarantee of revenue or interest from the districts which are to be benefited.

Concessions for toll bridges. Monopoly. *See also page 28.*

See page 168. RIGHT OF WAY.

Pre-emption. *See also page 38.*

Facilities and immunities. *See page 26.*

Guarantees. *See pages 29–34.*

Besides the condition referred to of load-carrying capacity, concessions for bridges are usually burdened with other conditions, such as—that there shall be a moderate tariff of tolls; that the bridge

Obligations of Concessionnaires. *See page 35.*

shall be of a certain width; that the roadway shall be of a certain material, and shall (with sometimes also the approaches) be maintained in good order by the concessionnaires, and well lighted; that Government traffic or troops shall be taken free or at reduced tolls; and that the community shall have the power of buying the bridge after a certain period, on terms agreed upon beforehand. It is of course important that these conditions shall be equitable and not weigh unduly upon the enterprise. Where a bridge takes the place of a previously existing ferry, it is sometimes also stipulated that in the event of the bridge being destroyed or becoming unsafe, the concessionnaires shall re-establish and maintain the ferry at the old rate of tolls till the bridge is again rendered available.

Maintenance

Toll railway bridges.

Although it is for road traffic that the great majority of toll-bridges are constructed, railway-bridges also sometimes depend for their revenue on tolls. This is especially the case in the United States, where railways and groups of railways are often divided by the great rivers which intersect the country; the expense of building bridges often forbidding their construction in the first instance when the railways are projected: the traffic being carried across by means of a floating bridge or ferry-boats, or by a long *détour* to the nearest bridge. The consequent inconvenience often proves so great as to induce capitalists to build a bridge as an independent enterprise. A competent engineer having been found to design the bridge, and trustworthy contractors who will build it for a certain sum, a company is formed with a capital based on this estimate of cost. The railway companies may then share the cost, or may agree to contribute a certain amount when the bridge is completed, or without contributing to the cost may engage to send a certain minimum amount of traffic over the bridge at pre-arranged rates of toll. Although cases of this sort are more usual in the United States, where many wide rivers have to be crossed, similar arrangements have been found necessary in Great Britain also; the Severn Bridge at Lydney, the Severn Tunnel near Bristol, the Mersey Tunnel at Liverpool, and the Forth Bridge in Scotland, affording examples of undertakings assisted in one shape or other by the contiguous railway companies who are interested.

Traffic guaranteed. *See page 29.*

Toll-bridge guarantees in United States.

In Great Britain.

Erection of bridges.

Manufacturers of bridges are generally called upon to erect them if the site be in their own country; and such a condition is made part of the contract. But, except in the case of very large or numerous bridges, the erection in a foreign country is seldom carried out by

Manufacturers unwilling to erect abroad. *See page* 51.

the manufacturers, as the undertaking is one not large enough to repay the trouble and expense such a course would involve. Although there are certain advantages in maintaining the responsibility of the manufacturer till the bridge is completed and tested by actual traffic, there is nothing so peculiar in the erection as to prevent a local engineer from undertaking it. If the bridge has been properly designed, and if the quality of the material and workmanship has been verified by inspection in the factory, and if the various pieces, after having been tried together by the makers, be properly marked, an experienced superintendent or skilled mechanic, furnished with a drawing, will have no difficulty in erecting a bridge he has not seen till it arrives on the site; and it is generally much cheaper to employ such a superintendent than to include the erection in the manufacturer's contract. Where, however, it is considered very important that the manufacturer should erect the bridge, he will be the more ready to agree to such a proposal if those risks which are to him unknown, but with which the purchasers in a foreign country are familiar, be removed. Thus the purchasers may agree to take the bridge material and tools from the ship's side at the port of arrival, and convey them to the site; to pay all dues and imposts; to provide necessary staging or flooring-timber free or at agreed rates; to furnish unskilled labourers; and generally to give all the advantages which their local knowledge may afford.

Local purchasers may grant facilities.

Choice of bridge, how determined.

In deciding upon the kind of bridge which shall best satisfy any particular case, various circumstances have to be considered, which may, however, generally be divided into three classes, as—

1. The Exigencies of the Site:
2. The Necessities of Manufacture:
3. Considerations of Economy.

Exigencies of the site.

1. *The Exigencies of the Site.*—The length of the spans into which a bridge shall be divided depends on the cost and convenience of numerous piers, as compared with those of long spans. The weight of an iron or steel structure depends primarily upon the span, because the weight per lineal foot increases with the distance between the supports; a bridge of 100 ft. span weighing about three times as much as a bridge of 50 ft. span, similar in all other respects.

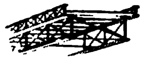
It is obvious that such a comparison depends upon the circumstances of each particular case; for, while a bridge at a low level

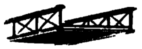
Short spans compared with long spans.

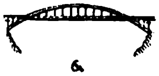
over a wide, shallow river, with a bed affording an easy foundation, may allow numerous piers to be cheaply constructed, a deep river running between high banks, or one offering impediments to subaqueous work, may render intermediate piers so expensive, as to make long spans preferable. The question of spans may also be affected by the necessities of navigation, which may require lofty and expensive piers to allow headway for passing vessels; or intermediate piers may obstruct too much the passage of flood-water or floating ice. On the other hand, long spans which obviate the need for piers or reduce their number may present special difficulties in erection. Such for instance would be the case in a bridge over the Bosphorus, where at a convenient crossing place the width is about 1750 ft.

Type of bridge determined by the levels.

From the present point of view, *i.e.* that which concerns the site, it will generally be found that the Levels of the bridge or the Approaches in their relation to the river, ravine, road, or railway to be crossed, primarily determine the type of superstructure; and the levels may forbid the application of certain systems which require parts of the structure to be too low beneath the platform of the bridge. The different kinds of bridges which are designed to meet this question of levels are illustrated by the examples that follow on pages 155 to 168. Where, in crossing a river, the level of the approaches is so far above the highest water that a bridge continued at the same level will leave ample room below the structure for the passage of vessels or floating trees, then the designer has free scope, and may make a "deck" bridge, namely with girders below the platform or roadway, although if of more than one span the piers may have to be lofty and expensive. But where a river has low banks, or where in time of flood the water rises nearly to the level of the approach roads, it may be necessary either to raise the structure, or to make sloping approaches, and construct a "through" bridge with as little as possible of it projecting downwards. Examples M to S (pages 162–5) show girders arranged in this way. If, however, the headway is wanted not for flood-water, but only for the passage of vessels, a clear headway in the centre of the bridge will suffice, and an arch, as in example K and L (page 160), or certain forms of bowstring girders (6) may serve the purpose without raising the structure. Where only foot passengers, horsemen, and cattle have to pass, the bridge floor may be arched, and in ancient times stone bridges were frequently made in this way (7), so as to combine low approach levels with a sufficient headway. The Rialto Bridge at Venice (shown


4.
Deck bridge.


5.
Through Bridge.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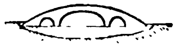
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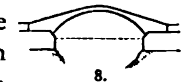

8.
Rialto.

here without the parapets and covered roadway), is an example, the ascent in this case being made by a series of easy steps.

Headway below bridge.

Approaches. *See* GRADIENTS, *pages* 63 & 3 1.

Indeed, it may be said that in many cases the points arising out of and connected with the levels form the key-note of the whole project. Thus, in the erection of a railway bridge, if the river conservators, or others whose consent is necessary, demand a considerable headway for the passage of vessels, the engineer of the railway may, in order to raise his train level, have either to make long approach viaducts or embankments, costing as much as or more than the bridge itself, or, to avoid this cost, make shorter and steeper approaches which may prove the "ruling gradient" of the railway, and permanently increase the cost of haulage. If, to avoid both these alternatives, an opening span in the middle of the bridge is permitted, it will not only add considerably to the cost of the bridge itself, but be a permanent source of expense and danger.

Thames bridges.

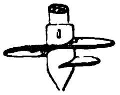
See page 173.

Somewhat the same difficulty arises in regard to road bridges where easy gradients are desired, but where headway over the river or railway or over streets and wharfs parallel to them, demand a considerable rise. The raised viaduct on the north side of London Bridge allows an easy approach, while on the neighbouring Southwark Bridge, where the viaduct is wanting, steep gradients are necessary. These opposing difficulties may be minimised by so designing the bridge as to reduce the thickness of the arch or floor. Westminster Bridge, also over the Thames, affords an example of this plan, the maximum headway for vessels being combined with low level approaches. Cases occasionally arise where these opposing conditions bring other methods under consideration. Such, for instance, are the lifting the traffic from low approaches to a high-level bridge by mechanical means or by the excavation of a tunnel.

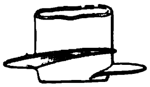
Iron piers.

Screw piles.

Whatever the kind of bridge, the Piers and Abutments should be considered separately from the Superstructure. The abutments may be built of masonry or brickwork, or even of timber; but the piers in the waterway, and sometimes also the abutments, may be best constructed of iron or steel. Such piers are composed either of piles, cylinders, or caissons. Screw-piles are made either as solid columns of wrought-iron or steel, or as hollow columns of cast-iron, the piles having in either case a screw at the point, so that when turned by a capstan the piles can be inserted into the ground till a firm foundation is reached. The length of each pile, as delivered at the site of the bridge, is determined partly by the necessities of manufacture, and partly by the exigencies of transport. Solid piles are generally of some diameter between 4 in. and 9 in., and can be rolled in lengths of from 10 ft. to 20 ft, according to their diameter and weight. The separate lengths can be united by couplings of various kinds, but the piles can, by welding, be made in one length without external flanges or projections of any kind, convenience for transport, however, generally limiting the length to 30 ft. or 40 ft. Cast-iron piles are generally made in pieces of from 9 ft. to 16 ft. long, and are united by internal or external flanges, or by sockets. When iron and steel are at an average price, solid piles properly prepared and jointed cost from £13 to £17 per ton, and cast-iron piles from £9 to £12 per ton. Iron piles are sometimes made without screws, and are driven into place by a falling weight: in such cases they are pointed at the ends, and, if of wrought iron or steel, are best made (Fig. 11) of a hollow, ribbed section. Pile piers are most frequently used for supporting spans of from 20 ft. to 70 ft., as beyond this span groups of piles would be necessary, and cylinders of larger diameter then generally become preferable.

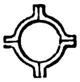


9.



10.

Average prices. *See* FLUCTUATIONS IN PRICES, *page* 443.



11.

Steel columns. *See also page* 864.

Pier cylinders.

Pier cylinders may be used either as hollow columns for supporting the load of the bridge, or as caissons to enclose solid columns of concrete or brickwork. The solid column is most usual for the submerged portion; ordinary iron columns, as would be used for a bridge on land, being erected above water. The cylinders are usually of some diameter between 3 ft. 6 in. and 16 ft., and are generally parallel, the base being sometimes coned out to obtain a large bearing area on the foundations The cylinders are in most cases of cast-iron from ¾ in. to 1½ in. thick. Made in lengths of from 4 ft. to 8 ft., and united by flanges, they are frequently (when over 5 ft. diameter) divided into segments, for convenience of transport. Although cast-iron is the most suitable material, the cylinders are, where there is very great risk of breakage, made of wrought-iron or steel plates, about ⅜ in. or ½ in. thick, riveted together and stiffened by L bars and ring-shaped frames. This material is best where caissons, generally rectangular, are used instead of cylinders. In almost all cases sinking is effected by weight, but as it is generally necessary to clear out the soil within, either to assist the cylinder or caisson to descend or to make room for the solid pier which is to be constructed, various auxiliary methods are applied. Unless rocks or large boulders are encountered, scoops or dredging buckets can be

Diameter and thickness of cylinders.

Fixing of cylinder piers.

Pumping from cylinders. *See* Pumps, *page* 626.

Pneumatic method.

Limits of depth.

Divers. *See* Diving Apparatus, *page* 841.

used from the top, even for depths exceeding 100 ft.; but in many cases it becomes necessary that workmen shall descend to assist the excavation. If the stratum be clay, the cylinder can be emptied of water by pumps, or, if the clay be not quite water-tight, kept free of water by pumps while the men are working; but if of gravel, sand, alluvial soil, or rock, pumps will seldom overcome the water. In such cases the men must work in the diving-dress, or an air chamber may be formed at the bottom of the cylinder, which may then be regarded as a diving-bell, the water being forced out by air-pumps. By means of an air-lock in the upper part of the cylinder or caisson access is gained to the air-chamber below. The excavated soil may be brought out through the lock or, in order to leave the latter unobstructed, through small locks at the sides. The difficulty becomes greater as the depth (and therefore the air-pressure) increases, and special arrangements become necessary when the cylinders have to penetrate more than 70 ft. from the surface of the water. The pneumatic system of sinking cylinders is somewhat expensive, and as the apparatus and preparations bear a high proportion to the total cost of small bridges, it is seldom used except for large bridges, divers being generally preferred. Great care is necessary to ensure the cylinders reaching a firm stratum not liable to be undermined or weakened by the scour of the water.

By using metallic piles or cylinders, the water-way of a river is less obstructed than by the more bulky masonry piers; but, except for this reason, the only superiority which iron or steel has over masonry is in the facility afforded during construction, as piles or cylinders can be fixed without the cofferdams usually necessary for masonry.

Brickwork cylinders for piers.

Mode of sinking brick cylinders.

Brick cylinders in India.

Cylinders of brickwork are occasionally used for bridge piers where the soil is loose or sandy, and especially in countries where iron and steel are expensive, and clay suitable for bricks is abundant. The cylinders are built upon the ground on a metallic ring or curb, and, the soil being excavated within by scoops, dredging-buckets, or sand-pumps, the cylinder sinks, additional brickwork being added above until the required depth is reached. The inside is then filled with concrete. If the soil be very loose, the cylinder—to prevent it sinking too rapidly—may be suspended during the process by iron rods attached to the curb plates. This system of brick cylinders was used—principally for wells—many years before the introduction of iron cylinders, and in more recent times it has been employed very extensively for bridges in India. Concrete, as being generally more conveniently obtained or applied than brickwork, is also used for pier cylinders, this being one of the many useful applications of this material.

Concrete cylinders. *See also page* 122.

In regard to the Superstructure of Bridges they may be classed in various ways, and each kind—Girder, Arch, Suspension, and Cantilever—again sub-divided into classes. In regard to the superstructure, it may be said concerning all types of bridges that the importance of selecting an appropriate form increases with the length of the span; the choice of design is then narrowed, a correct decision becomes more difficult, and an error in judgment, or departure from the exact form which may be the best for the purpose in view, tells with great effect.

Classification of bridges.

For spans between 30 ft. and 150 ft., iron or steel girders form the cheapest kind of superstructure, both for road and railway bridges, except in cases where natural or easily-formed abutments facilitate the construction of arched bridges, or where the levels or certain secondary reasons, which have been referred to, prevail.

Girder bridges generally the cheapest.

Following the classification given on page 136, the exigencies of site may include questions of transport and erection. If there be long inland carriage over bad roads, the parts must be made of moderate size and weight; and certain systems of construction give more facilities than others in this respect. Sometimes it is difficult to procure skilled labour, and designs must be adopted which do not require skilled mechanics at the site. In other cases, the want of timber, or the depth of water, renders the use of staging expensive or impossible, and bridges must be designed which can be erected from the shore or in some other way without staging. Thus, it may be so difficult or expensive to erect temporary staging, that girders may have to be launched forward from the shore and hauled over, and for this purpose must be so designed as to bear the strains they are subjected to during this operation. Or the superstructure may be built upon pontoons, then floated to the site and deposited on the piers by a falling tide or by partially sinking the pontoons by admitting water; or, being first deposited at a low level, may be raised by hydraulic machines. Or, when these methods are inapplicable, as in the spanning of deep ravines and rapid rivers, the bridges may be built forward as cantilevers.

Transport.

Erection without staging.

See page 168.

Floating to site.

Tides utilised.

2. *The Necessities of Manufacture.*—It is always expedient to utilise, as far as possible, the materials and modes of construction which

Necessities of manufacture.

Variety of rolled iron and steel.

See IRON *and* STEEL, *pages* 543-563.

Simple designs generally the best.

are most easily attainable; and in regard to bridges, these conditions are not everywhere the same. There is an immense variety of shapes and sizes of rolled iron and steel made for structural purposes, but some are much more expensive than others; and it is not always easy to obtain quickly small quantities of a particular kind. The design which requires the least weight of material may, for these reasons, be more expensive than a heavier and simpler design. If, for instance, in a small span the engineer were to vary the dimensions and thicknesses of the individual parts to accord exactly with the stresses to be endured by them, such a variety of sizes of rolled iron or steel might become necessary as would involve unremunerative trouble, expense, and delay, in the manufacture. For the same reason also, where designs are made in one country for manufacture in another, some latitude should be left to the manufacturer or superintending engineer in regard to the exact shape and size of pieces. Again, theory may in some cases prescribe as the most suitable disposition of material, curved or irregularly-shaped girders, but it may be taken as a general rule that the simpler the design the better. A variety of shapes and dimensions in the different parts—unless cheapened by the quantity of each and consequent economy which numerous similar parts allow—is to be avoided. Of course there may be secondary reasons which justify a reduction in weight, even at an increased cost in the manufacture; such reasons, for instance, as high rates of freight, or of import duty charged according to the weight; or a desire for what may be considered the more pleasing appearance of the curved or irregular girder.

Rivets *v.* pins.

European and American practice.

Riveted connections are generally considered by European engineers as stiffer and more durable than pin connections. In structures subjected to moving loads, and especially to the oft-repeated impact of railway trains, the pins, unless they are rendered permanently tight, are apt to hammer and become loose. And the necessary tightness cannot easily be assured with pins of less diameter than 4 in., so that even where pins might for other reasons appear desirable, they should not be used for spans where small diameters are appropriate. In the earlier bridges made in the United States the use of pins was carried to excess, and failures occurred not only because of the pins becoming loose and the nuts shaking off, but because of the unsatisfactory nature of the subsidiary connections such as those of the transverse bracing to the main girders, the suspension of the cross-girders from the pins by means of hangers, and the use in bracing of round rods with screws and angular cleats at the ends. In the best American practice, however, these faults have been abandoned, and stiffer riveted connections substituted in such cases. Rolled "eye-bars," or links, are also often used inappropriately.

Links and eye-bars.

In the case of triangulated girders of spans over 100 ft., it becomes more important than in smaller spans that the lines of actual stress through the various members shall coincide with those intended and provided for by the designer. This symmetry is rendered more certain when the convergence is to central points than where the connection is by groups of rivets. But while as part of such a pin system eye-bars may be appropriately used for the diagonals of the web always in tension, or for the bottom chords of deck-bridge girders, when they are used for the bottom chords of through bridges as is often the case in America, the absence of rivet-holes prevents a satisfactory connection between them and the transverse bracing. The best practice in such cases is, while retaining the symmetry of the pin system, to use, as in the best bridges made in Europe, flat bars strengthened by plates riveted on where the pin-holes occur, and so rendering them of sufficient sectional area to allow for the loss by rivet-holes where subsidiary attachments are made. But as much money has been spent in the construction of special machinery for making eye-bars, and it is convenient and economical to make large numbers of them exactly alike, their use is encouraged even where inappropriate. They should not be used for spans under 120 ft.

Eye-bars inappropriate.

Riveting must be well executed.
See page 762.

Riveting, to be effective, must be well executed; the holes in the different pieces must exactly coincide, and the rivets completely fill them, this condition being ensured by the use of powerful hydraulic riveting machines. Such machines are not only employed in the workshop but at the site of erection, in the form of portable riveters worked by portable engines. In cities where, as in London, high pressure water mains are available, hydraulic power generated a mile or more from the site can be utilised for riveting without noise.

Portable riveters.
See pages 493 *&* 763.

Considerations of economy.

3. *Considerations of Economy.*—In designing a bridge, the engineer has not only to satisfy the exigencies of the site and the necessities of manufacture, but has to conform to certain standards of quality and fitness which may be varied within very considerable limits. That is to say, bridges, like other engineering works, may be made either in a very strong and permanent manner, with the maximum accommodation, or in a manner less stable or convenient. Much, of course, depends upon the amount of money available, and in some

Cheap and imperfect structures.

cases necessity may compel the erection of a cheap structure affording limited accommodation, strength, or term of endurance, and involving additions, repairs, or renewals, at a comparatively early date. The points which are thus left open, and upon which the engineer can only advise those who employ him, are:—

Cost, how determined.

(*a*) The Material of which the bridge is to be made—wood, stone, iron or steel.

See page 146. (*b*) The Width of Roadway for convenience of traffic.

See page 147. (*c*) The kind of Roadway Material, which, according as it is made light as of timber, or heavy as of macadam or granite paving, will determine partly the necessary strength, and therefore the cost, of the structure which is to support it.

See page 148. (*d*) The amount of Moving Load which is to be provided for, and whether and how far exceptional loads, or possible increased loads in the future, are to be considered.

See page 150. (*e*) The Margin of Safety required; that is to say, whether the bridge when sustaining its maximum loads shall be strained to one-fifth, one-fourth, or one-third of its ultimate theoretical failing-point; and also the surplus iron or steel to be provided to allow for loss by rust or decay.

See page 152. (*f*) The degree of Ornamentation which is to be included in the design.

The above points may be further elucidated as follows:—

Bridge materials compared.

(*a*) *The Material of which the bridge is to be made.*—In countries where timber is plentiful and the climate favourable, *Timber* (either alone or in combination with iron tension rods) may be employed with advantage where economy is desired. Thus, in the United States, Canada, Russia, and Scandinavia, timber may be obtained cheaply; workmen are skilled in using it; and the climate is generally favourable. But the term of endurance in timber bridges is at best much less than with iron or stone; they occupy much space, they are liable to destruction by fire, and the limit of span is not great. Therefore, where the requisite funds are available, iron or steel is preferred even in timber-growing countries, and especially for railway bridges.

Timber bridges.

Stone bridges.

Stone is well suited for arched bridges, and so applied is both long-enduring and pleasing in appearance; but skill, not always available, is needed for constructing stone bridges, and for designing the temporary timber centerings on which the arches are built; strong abutments are needed to receive the lateral pressure of the arch; the high curve often renders the approaches inconveniently steep; and beyond a span of 100 ft. stone bridges are difficult of execution.

Brick bridges.

Brick arches are often preferred in countries where clay for bricks is abundant, where foundations are easily constructed, where the height is small, and where, therefore, numerous small spans will compare favourably in cost with long spans. In India, for example, long viaducts have in this way been constructed more cheaply than would have been possible with iron or steel girders.

Iron and steel bridges.

It is needless to enumerate the various advantages afforded by *Iron* and *Steel* in the construction of bridges; but in the case of foreign countries where engineering skill and appliances are wanting, the fact that bridges can be designed and manufactured in a distant country and conveyed in pieces to the site of erection, is alone a sufficient justification for their use. The application of iron and steel to bridge structures allows greater scope to the engineer than was possible when stone and timber were the only available materials; and as the great majority of modern bridges, or at least their superstructures, have been made of iron, it may be said that an entirely new field has been opened out to the bridge engineer. For some time after iron was used for the superstructure of bridges, the difficulty of erection prevented its application for bridge piers; but the invention of screw piles, and the numerous systems of cylinder piers and caissons have given to the engineer a choice of methods wide enough to meet almost every case.

Bridge piers.
See page 138.

Steel bridges.

The many modern inventions in connection with Steel have rendered it available, since the year 1880, for the construction of bridges; and the cost and selling price of steel, previously very high in proportion to those of wrought iron, have since 1890 been practically the same. Steel of the kind suitable for bridges not only has an ultimate tensile strength equal to from 27 to 32 tons per square inch, as compared with a usual range of 20 to 22 tons in iron, but the steel is more ductile and elastic than iron, allowing of easier working in manufacture and of greater durability afterwards against repeated shocks and strains. So long as steel cost more per ton than iron, a saving in weight was necessary to allow an equality in the cost of a bridge; but in small spans such a saving in weight could not be safely obtained because a certain thickness of parts must be allowed for wasting by rust. Small spans may, however, be made with advantage of steel of the same weight as in iron, because the extra strength and durability may be obtained without extra cost. It is, however,

See STEEL, *page* 560.

Steel for small Spans.

for long-span bridges, where the stresses in the structure are largely due to the weight of the material, that is to say where the weight of the structure itself has an effect great in proportion to that of the moving load, that the saving in weight by using steel is of the greatest advantage; and the limit of span is greatly increased, as is shown by the many long-span bridges that have been constructed. Where the expenses of transport to a foreign country, or of inland carriage, are great, the saving in expense by the use of steel is obvious.

Long-span bridges.

Width of roadway. *See Examples, pages* 155–165.

Width of vehicles.

London Bridge.

Marshalling of traffic.

Width of Thames bridges.

(*b*) *The Width of Roadway.*—The width of a railway-bridge is determined by the gauge, and by the railway having a single or double line; but a highway bridge allows considerable latitude within which cheapness may be obtained by narrowing the platform. If vehicles pass rarely, a bridge wide enough for one only may be sufficient, but in the case of long spans narrow bridges are objectionable, because of their deficiency in lateral stability. Assuming that the extreme width of a vehicle is, as in England, about 8 feet, then the width of the roadway, in addition to the footpath, should be made to accommodate a certain number of vehicles; 9 feet within the curb is considered sufficient for one; 18 ft. to 20 ft. for two; while on London Bridge, which may be taken as an example of a city bridge carefully designed, 35 ft. is the width provided for four lines of vehicles. By marshalling the traffic into two lines in each direction, the inner two lines being formed of quick and the other of slow vehicles, and by forbidding halting on the bridge, a much larger traffic may be accommodated than where such regulations are wanting. A width sufficient for three or five vehicles is sometimes adopted, as the space between the lines of traffic enables a quickly-moving vehicle to pass by a slow vehicle which is blocking the way. Southwark Bridge and Waterloo Bridges, on the Thames, are constructed in this way, each having a 28 ft. roadway, and two footpaths of 7 ft. Westminster Bridge has a total width of 82 ft., of which 54 ft. are given to the roadway, and 14 ft. to each of the footpaths. In country districts, bridges are sometimes made without separate side-walks for foot passengers, but in such cases the roadway must be wide enough, or recesses must be provided (generally over the piers), to allow for the safety of foot-passengers during the passage of vehicles or cattle. In wide bridges the cross-girders, if they rest on the bottom members of the main girders, must be long, and the depth of such cross-girders is sometimes inconvenient, as diminishing the headway below the bridge or involving steep approaches. By interposing a central main girder the span and depth of the cross-girder may be reduced. But in deck bridges, where the cross-girders rest on the top of the main girders, the roadway may be made to overhang so that the span of the cross-girders is reduced.

See Example R, page 164.

See Examples B to H, pages 155-9.

Roadway material.

(*c*) *The kind of Roadway Material.*—The selection of roadway material is governed by the kinds which are obtainable in the neighbourhood of the bridge, by the nature of the traffic, by the climate, by the degree of permanency desired, and finally, by the weight of the material itself, and the consequent strength required in the bridge to support it. Timber is the lightest material, but if used as part of the structure will not last long, and is subject to destruction by fire. It is in cold dry climates that timber is oftenest used for highway bridges, an upper layer of wearing planks, which can be renewed, being placed upon a complete timber platform. Timber blocks may be used on iron highway bridges, and such a roadway weighs from 40 lbs. to 60 lbs. per square foot of surface, including 8 lbs. for gravel, bitumenised ashes, or asphalte, on which to bed the blocks. Macadam is commonly used on highway bridges, and from 8 in. to 14 in. of macadam, or macadam on concrete, is generally adopted, the exact thickness depending on the nature of the traffic. For every inch in thickness of concrete or macadam, a weight of about 10 lbs. per square foot of surface is imposed. In cities where heavy traffic must be provided for, granite blocks on concrete are often used, and for this kind of roadway a weight of from 200 lbs. to 300 lbs. per square foot should be allowed. Macadam is sometimes placed on a timber platform; but for any of the materials enumerated above, except wooden planks and blocks, a complete platform of iron or steel plates should be provided. Generally, rolled plates, either flat, curved, buckled, or corrugated, of from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. thick, are used, and as such plates, including fastenings and connections, add from 12 lbs. to 25 lbs. per square foot to the weight of the bridge, the cost of the structure is increased. Very great care, both in design and workmanship, is necessary to keep the platform of a wrought-iron bridge water-tight, especially under railway traffic. Cast iron is admirably adapted for the platforms of highway bridges which have to sustain very heavy loads; such plates are made in various forms—flat, ribbed, buckled, or corrugated; they can by caulking be made permanently water-tight, and they are more lasting against rust than wrought-iron or steel plates. In the case of a strong cast-iron arched bridge to

Timber platforms.

Wood blocks.

Macadam.

Granite blocks. *See page 161.*

Platform of iron plates. *See page 864.*

Iron platforms seldom water-tight.

Cast-iron plates. *See Example* L, *page* 161.

carry heavy city traffic, with a roadway either of granite, macadam, asphalte, or wood blocks, a substratum of concrete on cast-iron plates is the best that can be adopted. In London, Southwark Bridge over the Thames, and the Holborn Viaduct over Farringdon Street, afford examples of this combination.

Railway bridges without deck. *See Example* B, *page* 155; *and also* RY. EQUIPMENT, *page* 683.

In railway bridges the cheapest plan is to have no deck or roadway material, but to lay the rails upon longitudinal or cross sleepers placed directly upon the bridge framework. Such a plan has been frequently adopted where cheapness was desired; but as sometimes the trains have left the rails on such bridges, and the sleepers, unable to resist the shock, have given way and allowed the train to fall through, the system is seldom now adopted, and is often forbidden by laws or official regulations. In the best railway bridges a platform of iron or steel plates is constructed, upon which ballast can be laid, so that the ordinary system of permanent way is unaltered: the ballast acts as a cushion on which the trains run smoothly and with the minimum of noise, and there is no danger from fire. In other cases, where the rails are laid on longitudinal or cross-sleepers without ballast, a complete deck of strong planking is provided, resting on cross-girders sufficiently near together to sustain a train which has left the rails; and such a deck can be covered with sand, ashes, or sheet-iron, to render it uninflammable. Guard timbers should be placed at the sides of the rails to keep a train from leaving the track. In cities, railway bridge-floors must be water-tight.

Ballast on bridges. *See Example* R, *page* 164.

Wood deck for railway bridges.

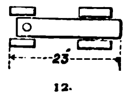
See page 683.

Moving loads.

(*d*) *The amount of Moving Load to be provided for.*—The weight of a crowd of persons has been estimated by different engineers at from 60 lbs. to 100 lbs. per square foot, although on a small area, as in the crowded entrance to a theatre, a greater weight may be concentrated. Men placed close together on a weigh-bridge have been found to impose a load of 84 lbs. per square foot, and with any greater density movement would become impossible. With regard to the weight of vehicles on a bridge, it is seldom that an average load of more than 45 lbs. per square foot, or 360 lbs. per lineal foot of each line of traffic, is put upon the whole surface of a bridge, except in the case of small spans (say under 50 ft.); and even London Bridge when most crowded would probably not have more. The effect of loaded vehicles depends greatly on the length and width of the space covered by the vehicles, their overhanging loads, and the horses, and on the length and width of the wheel base. In England a vehicle weighing 12 tons, on four wheels with a wheel base of 10 ft.

Weight of a crowd.

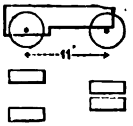
Weight of vehicles.



12.

Traction engines. *See page* 599.

and a wheel gauge of 5 ft., is seldom exceeded. A heavy traction engine imposes a load of 280 lb. per square foot, and a steam road-roller 336 lb. Provision must therefore be made in the strength and arrangement of the cross-girders and other local parts which may have to sustain concentrated loads. But even with occasional loads of this kind, one such vehicle and the rest of the bridge loaded with 80 lbs. need be alone provided for. In the case of spans under 40 ft., it will be found that the necessity for providing for a concentrated local load will bring up the average for the entire surface much higher than for the longer spans, while for spans longer than 100 ft. a less load may be assumed, although for these longer spans, in cases where heavy road material is used, it is of small consequence whether the moving load be a little more or less, as such a circumstance has but slight effect on the total strains on the bridge. There are no official rules in England for the loads on road bridges. The standard in France is 200 kilos. per square mètre = 41 lbs. per square foot. Troops on march, 21 in. in rank and 30 in. pace, occupy 4·37 superficial feet per man, and (allowing 154 lbs. per man) impose a load of 36 lbs. per square foot. The following may be taken as safe limits for moving loads, the exact weights depending on the locality and likelihood of heavy traffic:—



13.
Road rollers.
See page 601.

Prescribed loads.

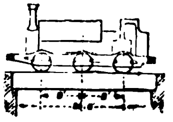
Safe limits of loading.

Bridges under 40 ft. span	120 lbs. to 150 lbs. per square foot.	
Bridges 40 ft. to 100 ft. span ..	80 lbs. to 100 lbs.	,,
Bridges more than 100 ft. span ..	70 lbs. to 80 lbs.	,,

In the case of railway bridges for standard-gauge lines 1½ ton per lineal foot for a single line, and 3 tons per lineal foot for a double line, are loads seldom exceeded. But for spans shorter than 40 ft. the concentrated load of a heavy engine with a short wheel-base will tell with greater effect, and the bridge should be made stronger accordingly. For example, with a heavy tank-engine, weighing when equipped 48 tons on a wheel-base of 16 ft. (this being an example of the heaviest concentrated weight of an English locomotive), a load equal to a disturbed weight of nearly 2½ tons per lineal foot would be imposed on a bridge of 20 ft. span, although, since the extreme length outside the buffers would be 30 ft., no more than 1½ ton per lineal foot could be imposed on a bridge of 100 ft. span, if a train of such engines were placed upon it. In cold climates a bridge may be loaded with snow and have in addition a rotary snow plough pushed by three locomotives. In the official regulations of

Moving loads on railway bridges.

Heavy engines on short wheel-base.
See page 696.



14.

Prescribed loads for railway bridges.

Safe limits of loading.

most countries, it is considered unnecessary in the case of long-span bridges to provide for a load of locomotives all over the bridge, and beyond 100 ft. span the 1½ ton per lineal foot for each line of way is reduced. The following are safe limits of moving loads for standard-gauge railways:—

For spans up to 20 ft. 2½ tons per lineal foot (for each line).
,, 20 ft. to 50 ft. 2 ,, ,, ,,
,, 50 ft. to 80 ft. 1¾ ,, ,, ,,
,, 80 ft. to 120 ft. 1½ ,, ,, ,,
,, above 120 ft. 1¼ ,, ,, ,,

Locomotives heavier than formerly.

See LOCOMOTIVES, *page* 697.

In regard to the loading of railway bridges, it must be borne in mind that locomotives have been made much heavier than formerly; and as the use of heavy steel rails facilitates the employment of heavy engines, a still further increase of weight must be looked upon as possible by the bridge designer. On the other hand, modern locomotives are designed with more regard than formerly to an equal distribution of the load on the various wheels, and this of course reduces the local pressure upon the individual cross-girders of a bridge.

Margin of safety.

Dead and moving loads considered separately.

Factor of safety.

(*e*) *The Margin of Safety required.*—There are various ways of estimating or expressing the margin of strength which is given to a bridge. Generally the dead weight and moving load are added together, and the strain upon the steel due to the total load thus obtained is compared with the supposed breaking strain of the steel. But by some engineers the dead and moving loads are considered separately, the former being treated as constant, and the latter (as the one to which wear and tear, vibration and possible accidents will be due) being taken as the important factor. From this point of view the degree of safety is stated according to the number of times the moving load may be multiplied before the bridge will break. There are also more alterations of stress upon some parts of a bridge than on others. Thus the cross-girders, while fully strained when a train passes, may have no strain when the bridge is empty, and such frequent and extreme changes tend to weaken the girders. On the other hand the main girders, having always to sustain the dead load of the bridge, will not be so much affected by the passage of a train. That is to say, the *Range of stress* has also to be considered, although it was ignored in the earlier iron bridges and until the failure of certain structures showed the importance of it. For apart from the amount of the maximum stress, the degree of variation is of importance and there is a wider range in some parts of a structure than in others. In a bridge of small span the weight of the structure itself will impose only a small proportion of the total strains on the parts, the larger proportion being due to the moving loads. But in a long-span bridge the weight of the structure will be the principal factor, and the additional effect of the passing load will add but slightly to the total. In such a bridge therefore the range of stress in the main girders is small while in the cross-girders it is severe. The greatest change of stress occurs in those parts which are subjected to alternate tension and compression. This range of stress, as well as the maximum stress, should be held in view in determining the factor of safety. Thus, if 5 tons per inch be deemed a safe normal strain for iron, some parts should not be strained more than 2 tons, and others may be safely subjected to 6 tons. Or if steel be the material, with a safe normal stress of 6½ tons, then 3 tons and 8 tons may be the proper limits.

Range of stress.

Although the method of stating the margin of safety by a comparison of the working load with a breaking load is usual, and has therefore been followed here, it should be observed that a bridge will be irreparably damaged with a load much less than that which would break it. The limit of elasticity in iron, or the point at which it ceases to recover its shape after a strain is removed, is generally about one-half of the ultimate or breaking limit, and in steel about three-fifths. Thus in a bridge made of iron equal to a breaking strain of 20 tons per square inch, 9 or 10 tons per square inch would probably be its limit of elasticity, and in steel of 28 tons, the limit ranges from 15 to 17 tons; and if once loaded beyond this point it would never recover from the stretching or deflection it had undergone. And as the joints and other parts would have been permanently elongated, they would be more liable than before to become rusty or loose; and the term of endurance of the bridge would be reduced, even if such a heavy load were never again applied.

Excessive loads.

Limit of elasticity.

See IRON & STEEL, *pages* 546, 560.

Evil effect of over-straining.

Regard should also be given in the calculation to another important consideration, which is only slightly due to the moving load, namely, the deterioration of the bridge by rust—a point which is unfortunately often neglected. Although there has not yet been sufficient experience of modern steel bridges to allow an exact estimate of their term of endurance, the experience already accumulated shows that while bridges of the strength given by the best engineers will last, even under railway traffic, for a very long time,

Deterioration by rust.

Painting of wrought iron.

if they are so designed as to allow access to all parts for painting, and if the painting is properly attended to, yet, owing to the neglect of these conditions, iron bridges have rapidly deteriorated. England, because of its climate, affords conspicuous examples of the effect of rust, especially in towns where there is a vitiated atmosphere, and the painting is too often considered a matter of small importance. The first painting of rolled iron or steel, if done only in the ordinary way, is of far less consequence than the proper painting after the first coatings of paint have decayed: for unless the black scale, or peroxide (formed on the iron by its contact with the air during rolling), is removed, as is customary only as a preliminary to galvanising, neither oiling nor painting will permanently prevent the scale from coming off. Very slight differences in the chemical constituents of steel, or even in the temperature at which the last work in rolling has been done, seem to have considerable effect in rendering it liable to rust. On the whole steel is more susceptible than iron. Cast iron is much less vulnerable than rolled iron or steel, and it is easier to preserve its outer skin by paint. Since the year 1880 a great number of the earlier railway bridges have had to be strengthened and renewed owing to the deterioration by rust, increased by the effect of heavier rolling stock.

Ornamentation of bridges.

See page 137.

Design limited by levels or vested interests.

(*f*) *The Degree of Ornamentation.*—Iron bridges, especially girder bridges, often offend the eye by their shape or obtrusivenesss, and the engineer is blamed for a want of taste in his design. Too often, however, the exigencies of the site render it impossible to give a graceful appearance in a structure which has to carry certain loads; and although sometimes the difficulty might be overcome by a moderate expenditure of money, the engineer is not always master of the situation. One of the most frequent difficulties is that arising from the levels, and certain forms of structure become necessary which could be avoided if the engineer had free scope in his design. Where an engineer is not restricted by secondary considerations or vested interests which limit his choice of design, it will generally be found that the form of bridge which is, constructionally, best suited for the purpose in view, is also the most appropriate in appearance, except in the opinion of those who would banish iron and other modern facilities altogether. An arched bridge may, in a city, if æsthetic reasons prevail, be often substituted with advantage for a girder bridge, even where the construction of artificial abutments will involve an expenditure of money not needed for a girder bridge.

In regard to appearance, an arched bridge has the great advantage that, while occupying in the centre of the arch but little of the headway below the platform, the parapet is the only part of the structure which projects above it, while the same headway could only be obtained below girders of similar span by having them high above the roadway.

Arched bridges. *See Examples* K & L, *page* 160.

In cases where girders can be placed below the roadway, the design of the parapet-railing, the lamps, and other supplementary details, may be arranged in different ways, according to the money at command. An engineer should always be informed whether purely utilitarian considerations are to prevail, or whether some latitude in regard to ornament is to be allowed him.

Supplementary details.

Lamps and parapets.

The circumstances which determine the Choice of System in bridge-building are so various, and produce such numerous combinations, that designs can seldom be exactly repeated, and it is for this reason that bridges cannot conveniently be tabulated in regard to form, dimensions, weight, and cost in the manner common with other engineering manufactures, such as steam engines or machines, which, being self-contained and almost independent of site, are catalogued with precision. In a country like Great Britain, intersected by numerous roads, railways, canals, and navigable rivers, the engineer in designing a new bridge has the choice of form or system greatly narrowed by the numerous vested interests which prevail, and which demand a conformity to levels and other conditions which he cannot escape. In more newly-settled countries, the engineer is free from many of these restrictions, and can choose a design best suited to the interest he has immediately in view; and can especially do so where the Government of the country assists by granting facilities or immunities. Not only, however, is there free scope for design in such cases, but economy may be often obtained by making of similar type and span numerous bridges, the roads and other works that follow after being made to conform to the bridges which precede them. This plan allows also much saving in the time of manufacture, as the designs, patterns, and even parts of the bridges may be kept in readiness.

Designs seldom repeated.

Freer scope in new countries.

It is not, however, attempted here to classify bridges according to any scientific method, but rather to show that there are certain rules enforced by the exigencies of the sites which apply to all kinds of bridges. To show clearly the variety in design which prevails to

Variety illustrated by examples.

See pages 155–160.

See pages 162–165.

meet different cases, the following eighteen examples of bridges have been selected, each of similar span, but fulfilling very different requirements; and not only might this list be greatly extended, but, as will clearly appear from the nature of the differences, they might be interwoven, combined and multiplied without difficulty into one hundred or more variations. As was seen on page 137, the position of the superstructure in relation to the level of the roadway is the point of view from which the different bridges are classed. In examples A to L of "deck" bridges, the load is carried on the upper part of the structure, which thus projects below the roadway. In examples M to S of "through" bridges, the load is carried on the lower part of the structure, thus affording a freer headway below the bridge platform. In regard to the form of elevation, the possible variety is too great to be enumerated here, and only some of them are incidentally referred to in the following list.

Assumed quality of iron.

See IRON, *page* 546; STEEL, *page* 560.

The wrought iron used in England for bridges is of a quality equal to a breaking strain of from 20 to 22 tons per square inch, and steel of from 27 to 32 tons. In the following examples steel of a quality equal to 28 tons has been assumed, and a working strain of 6½ tons under the maximum load. Wasting by rust has also been allowed for.

Cost of bridges depends on current price of iron.

See FLUCTUATIONS IN PRICES, *page* 443; STEEL, *page* 561.

Cost of erection.

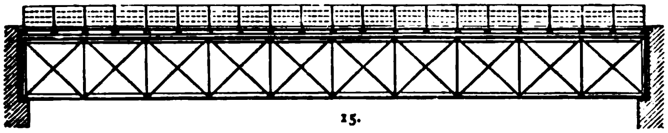
How determined.

The cost of an iron or steel bridge of course varies according to the current prices of the plates and bars of which it is composed; and in the following examples, while the different systems of construction would, in regard to cost, not alter much in relation to each other, the actual price of any bridge at a particular time would depend upon the prices then current for iron and steel. During the twenty years ending 1898 the prices of iron plates and bars as used in bridges ranged from a minimum of £5 per ton to a maximum of £12. Steel, which in 1880 cost about £5 per ton more than rolled iron, in 1898 cost about the same. The cost per ton of the bridges given in the following examples may be approximately estimated by adding from £6 to £10 to the current cost of iron or steel, the lower rate being added for bridges like examples J or R where the weight and repetition of parts are considerable, and the higher rate for bridges like examples A or M where the weight is small in relation to the labour required. Such an estimate would include the carriage to the port of shipment in the country of manufacture, but not the cost of erection on the site. From £2 to £5 per ton are limits which will embrace the cost of erection in the great majority of cases, the exact cost being determined by the nature of the site, the need of staging, the difficulty of fixing staging, the cost of labour, and other similar circumstances. The Examples treat only of the superstructure, as the piers are even more dependent on local circumstances, and must be treated accordingly.

Piers.
See page 138.

Foot-bridge 6 ft. wide.

Example A.—A bridge 100 ft. span and 6 ft. wide, for carrying foot passengers or beasts of burden, equal to a moving load of 80 lbs. per square foot. The bridge is composed of two main girders 10 ft. deep, placed 5 ft. apart, and braced together below the platform.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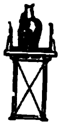
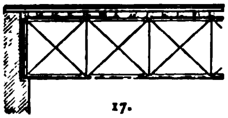

16.

Cross beams of timber, bolted on to the girders at intervals, support a platform of longitudinal or diagonal planking. A light wrought iron railing is fixed at each side. The iron or steel work would weigh about 10 tons.

Single-line railway bridge.

Example B.—A bridge 100 ft. span and 10 ft. wide, for carrying a single line of standard-gauge railway equal to a moving load of 1½ tons per lineal foot. The bridge is formed of two main girders 10 ft. deep, placed 5 ft. apart, and braced together; cross beams of timber support the longitudinal sleepers, to which the rails are spiked. Longitudinal planking between the rails serves as a footpath; guard-timbers are placed along the edge of the platform, but there are no parapets. The ironwork would weigh about 24 tons, or if of steel about 22 tons.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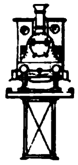
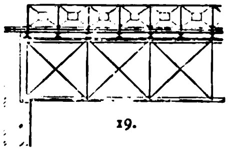

18.

Single-line railway bridge.

Example C.—A bridge 100 ft. span and 14 ft. wide for carrying a single-line standard-gauge railway, equal to a moving load of 1½ tons per lineal foot. The bridge is formed of two main girders 10 ft. deep, placed 8 ft. apart, and braced together. Cross-girders are placed 10 ft. apart, and attached to them are steel longitudinal rail-bearers, supporting cross-sleepers of timber 2 ft. 6 in. apart, to which the rails are attached in the ordinary way, by chairs or spikes. Between and outside the rails a deck or platform of planking is provided, and there is a light parapet-railing. The bridge if of ironwork would weigh about 38 tons, and if of steel about 34 tons.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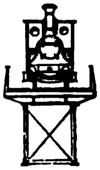
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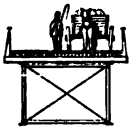
Highway bridge 18 ft. wide, with timber roadway.



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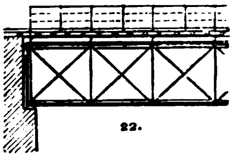


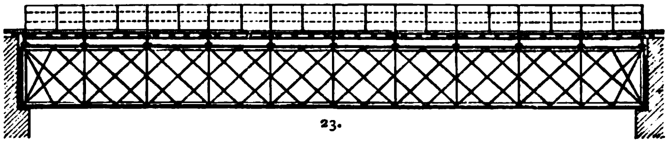
22.

Example D.—A bridge 100 ft. span and 18 ft. wide, for carrying highway traffic equal to a moving load of 80 lbs. per square foot. The bridge is formed of two main girders 10 ft. deep, placed 14 ft. apart, and braced together. Upon steel cross-girders 5 ft. apart a platform of longitudinal planking 4 in. thick is placed, and there is an upper surface of wearing planks which can be renewed when required. A strong iron parapet-railing is fixed on each side. The weight of steel-work would be about 33 tons. In a bridge of this kind the longitudinal planks should be laid with 1 in. space between them, so that the air can circulate; and if the timber is of good quality, such a platform will last for many years in any but an exceptionally destructive climate. A bridge of this description is not only strong enough to sustain an average load of 80 lbs., but the concentrated load of a waggon with 5 tons on each pair of wheels. It would not be strong enough to carry a heavy traction-engine safely.

See pages 148 & 600.

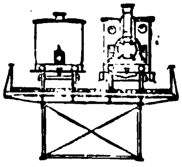
Double-line railway bridge.

Example E.—A bridge of 100 ft. span and 26 ft. wide, for a double line of standard-gauge railway equal to a moving load of 3 tons per lineal foot. The bridge is formed of two main girders 10 ft. deep placed 16 ft. apart, and braced together. Steel cross-girders are placed 10 ft. apart, and attached to them are longitudinal rail-bearers; and on the framework thus composed are cross timbers or sleepers, to which the rails are spiked, and there is also a complete deck of planking. The timber alone would impose a weight of about 25 lbs. per square foot, or 650 lbs. per lineal foot of bridge. On each side of the bridge is a light wrought-iron railing. The steel and iron-work would weigh about 64 tons. A bridge of this kind, as compared with a similar bridge half the width for a single-line railway, requires main girders stronger and heavier approximately in a similar proportion, *i.e.* double that of the narrower bridge; but the cross-girders, being of longer span, would be more than twice as heavy as in the narrower bridge. The



23.

Weight of wide and narrow bridges compared.



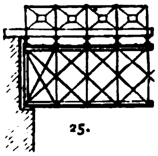
24.

alternative plan, therefore, presents itself of having three or four main girders instead of two, and so reducing the span between the bearings of the cross-girders. There are, however, certain parts of the main girders which cannot in practice be reduced in weight exactly in accordance with the diminution of the loads, and therefore some of the saving effected in the cross-girders would be lost in the additional weight which the three or four light main girders would have as compared with the weight of two main girders. Each case must be considered on its own merits according to the span, the loads, the depth of girder, and other circumstances.

See Examples G, H, J.

Highway bridge 32 ft. wide with macadam roadway.

Example F.—A bridge 100 ft. span and 32 ft. wide, for carrying heavy highway traffic equal to a moving load of 100 lbs. per square foot. The bridge is formed of three main girders 10 ft. deep, placed 11 ft. apart, and braced together; and resting upon them are cross-girders 5 ft. apart, which project as cantilevers to carry the footpaths. A platform of corrugated plates, riveted to the cross-girders, carries the road macadam, which is 4 in. thick on 8 in. of concrete, the plates and the road material together imposing a dead load of about 160 lbs. per square foot on the bridge. On each side is fixed a strong iron railing. The bridge could be divided into a carriage way of 18 ft. to 20 ft., sufficient for two lines of vehicles, and two footpaths of 6 ft. to 7 ft.; asphalte $\frac{3}{4}$-in. thick on the concrete being substituted for macadam at the footpaths. A moving load of 100 lbs. per square foot of the entire surface being assumed, the local supports are also strong enough to allow a traction engine to pass safely if a maximum load of 10 tons on any one pair of wheels be not exceeded. The weight of steel and iron in the bridge would be about 98 tons. As the central main girder has to be made stronger than the side girders, it is sometimes preferred to have four similar girders, in fact to place two single-line bridges side by side. In very long spans, lateral stability is obtained by placing the two structures some feet apart and bracing between.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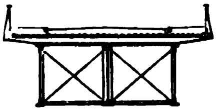

26.

Corrugated iron. *See pages* 147 & 552.

See page 148.

The foregoing examples, A to F, are alike in having riveted girders of the trellis or lattice kind; in having a depth one-tenth of the span; and in having the roadway upon the upper part of the girders. This mode of placing the roadway is that usually adopted where circumstances permit; and it may be taken as the best and

Roadway above the girders generally.

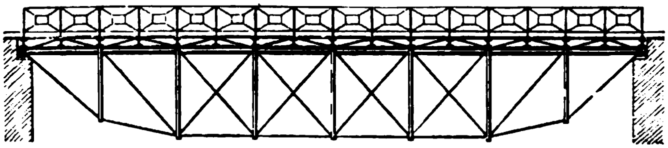
simplest method according to the English system, although the want of headway below the bridge often forbids its adoption. *See page 137.*

A saving in weight and cost may be sometimes obtained by making the depth more than one-tenth of the span; but as girders so proportioned require extra stiffening and bracing, they are not always advantageous.

Shallow girders. Girders are frequently made of a depth much less than one-tenth of the span; one-twelfth is very common, and from one-fifteenth to one-twentieth were considered proper proportions in the earlier days of iron-girder making. Proportions of 1 in 15 are still occasionally adopted, and 1 in 20 may be taken as the limit even for continuous girders. Shallow girders are useful when the headway below the bridge is limited; but they require a greater expenditure of material than deep girders of equal strength, and such abnormal proportions are only adopted where the exigencies of the site demand them. **Deflect more than deep girders.** Moreover, even when the same strength, as represented by the load-carrying capacity is given, a shallow bridge is less rigid, and deflects more than one with a well-proportioned depth. Example J shows a means of minimising this difficulty.

Plate girders. Plate-girders (so called from the web being of a solid plate, as distinct from the open lattice or trellis web) which for girders of ordinary proportions are suitable for spans up to 50 ft., are generally preferable also for spans up to about 100 ft., where the depth is limited to 1 in 15, as the greater weight of steel necessary for such shallow girders can be so conveniently applied. The three systems of deep, medium, and shallow girders would then compare approximately as shown in Examples G, H, J, if applied to a bridge of width, platform, and load-carrying capacity the same as Example F.

Deep truss girders.



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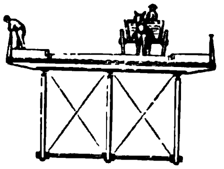
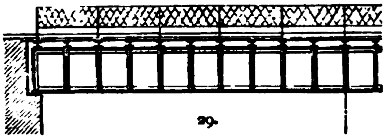


28.

Example G.—A steel bridge with a roadway 32 ft. wide, composed of three pin-connected trussed girders, 14 ft. deep, placed 11 ft. apart and braced together, would weigh about 84 tons.

Plate girder bridge.

Example H.—A bridge of similar width and strength, but composed of three plate girders, 7 ft. deep, would weigh about 100 tons. Where, however, the headway below a bridge is so limited as to require such shallow girders, the necessary strength may generally be best given, as in Example J, by numerous girders placed near together, requiring no cross-girders.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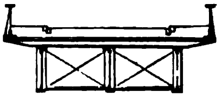
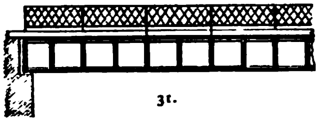

30.

Highway bridge 32 ft. wide without cross-girders.

Example J.—A bridge 100 ft. span and 32 ft. wide, for carrying highway traffic. The bridge is formed of seven main girders, 5 ft. deep, placed 5 ft. 4 in. apart, and braced together. There are no cross-girders, but a platform of steel or wrought-iron plates is riveted directly to the top flanges of the main girders, of which indeed, they form to some extent, by such an arrangement, an effective part. The roadway material, the parapets, and the strength of the bridge per square foot, are similar to those in Examples F, G, H. The weight of iron would be about 162 tons. It will be observed that in a bridge of this kind the depth or thickness of the structure is kept down not only by the moderate depth of the main girders, but by the absence of cross-girders.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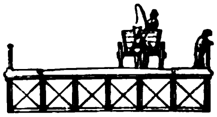

32.

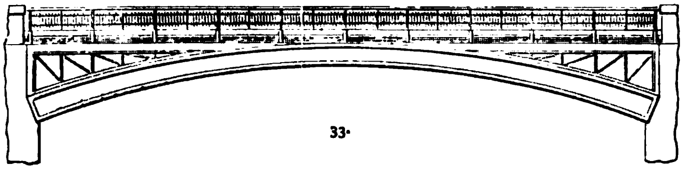
Still within the class of Bridges which have the roadway above the structure, an arched bridge, as in the following Examples K and L, allows the minimum depth of parts below, if a cross-section only at the centre of the span be considered; and if the headway below be needed for the passage of masted vessels, sufficient height at the centre of the arch alone is necessary. If, however, the height of the headway below the bridge is determined, not by the height of masted vessels, but by the level of flood-waters which must pass, or of floating

Arched bridges allow maximum headway.

ice or trees, headway in the centre only of the arch would not be sufficient: and it is besides undesirable that the springing of the arch should ever be below the water, though the arch would leave sufficient headway if unmasted boats only have to pass, and if the flood waters reach only to the level of the springing.

Steel arched bridge.

Example K.—An arched bridge 100 ft. span, and 32 ft. wide, for carrying highway traffic equal to a moving load of 80 lbs. per square foot of surface, or a vehicle having as much as 8 tons on one pair of wheels. There are seven main ribs of steel, having a depth of 2 ft. 6 in. (one-fortieth of the span) at the crown of the arch, braced together transversely by lattice frames. The platform is made of 6 in. planking, laid transversely on the arches, with wood roadway blocks, 4 in. deep, bedded on the planks in asphalte. The carriage-way is 20 ft. wide, for a double line of vehicles, and there are two footpaths, each 6 ft. wide, of narrow oak planking. The parapets are formed of wrought-iron railings, with cast-iron standards. The steel and iron work would weigh about 62 tons. Strong abutments are necessary.



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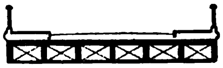


34.

Cost of abutments must be reckoned.

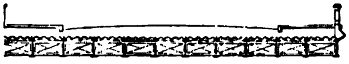
In comparing the cost of a bridge of this sort with that of a girder bridge, not only the greater cost per ton of the arches as compared with parallel girders, but the cost of the abutments also, must be taken into account. In an arched bridge the abutments must be stable enough to resist the horizontal thrust of the structure, and not, as in a girder bridge, a vertical load only, and the cost of the abutments would depend mainly upon the suitability of the soil for foundations, and the cost of building materials.

Cast-iron arched bridge.

Example L.—An ornamental cast-iron arched bridge, 100 ft. span and 53 ft. wide, suited to carry the heaviest street traffic of a city, a moving load of 100 lbs. per square foot being assumed, the bridge being also strong enough to carry a traction-engine or a steam-roller of the heaviest kind made up to 1898. There are twelve cast-iron

See page 148 & 602.

main ribs, each formed in three pieces bolted together, and 2 ft. 6 in. deep at the crown of the arch, the ten inner ribs being of a plain I section, and the two outer ribs having bold mouldings and ornamental spandril-fillings. Transverse bracing-frames of cast iron connect the main ribs, and support a platform of cast-iron corrugated plates, bolted together and made water-tight by caulking. The carriage-way is 35 ft. wide, sufficient for four lines of vehicles, the road being formed of granite blocks 8 in. deep, bedded upon concrete. The footpaths are each 9 ft. wide, formed of stone slabs on concrete, the dead weight of plates, concrete, and paving averaging 300 lbs. per square foot over the entire surface of the bridge. On either side there is a strong parapet of ornamental cast iron. The weight of ironwork would be about 420 tons, and the cost from £12 to £14 per ton. The cost of decorative painting or gilding and of lamps is not included above, nor in any of the previous examples. As a considerable part of the cost would be incurred for patterns and special preparations, the cost per ton would be reduced by 2 to 10 per cent. in a bridge with two or more similar spans, as these expenses would be divided over a larger tonnage. Cast iron is the material best suited for an iron arched bridge with a heavy dead load, as in this example, and—except where the cost of transporting the heavier weight and the risks of breakage during transport are very serious—is superior to wrought iron or rolled steel, because while sufficiently elastic and strong against compressive strains, it is less liable to deterioration by rust. The weight and stability of cast iron is specially suited to heavy roadway material and heavy traffic. Southwark bridge and the Holborn Viaduct bridge are examples in London.



35.—CROSS SECTION AT CENTRE.

Cast-iron roadway plates. *See page 147.*

Heavy road material.

Cast-iron arched railway bridges.

See page 147.

Following the classification adopted on page 137 of bridges designed to meet the exigencies of levels, all the preceding examples belong to the category of bridges with the roadway on the upper part of the structure. The examples that now follow belong to the second category, of bridges with the roadway on the lower part of the structure—a system seldom preferred except when the limited headway under the bridge forbids the opposite system. For where the girders are above the platform it is obviously impossible to brace between them, unless the bracing can be placed high enough to be clear of the traffic on the roadway. In bridges over a railway or a tramway headway to clear the engine chimney or the car is necessary, and in bridges over highways a clear height for loaded wagons. In cases

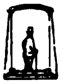
Bridges with the roadway on the lower part of structure.

See pages 166 & 309.

where the girders are not high enough to allow this, they must be stiffened in some other and generally more expensive way. As it is usually necessary in bridges of this kind that the main girders shall be the full width of the roadway apart (except where the footways are carried on brackets outside the main girders, or where there is a central main girder), the span of the cross-girders is greater than when they can (as in Examples A to H) be made to overhang the main girders, so reducing the span between their bearings, and consequently their weight and cost. Against the cost thus incurred in bridges of this kind, known sometimes as "through" bridges, must be set the saving in parapets, the girders themselves partly serving for that purpose.

Foot bridge 6 ft. wide.

Example M.—A bridge 100 ft. span and 6 ft. wide for foot passengers or beasts of burden, equal to a load of 80 lbs. per square foot. The bridge is formed of two main girders 10 ft. deep, braced together at the top. Resting upon and riveted to the bottom flanges of the main girders, or suspended to them by bolts, are T or L bars, serving as cross-girders, on which are placed longitudinal timbers, to which a plank floor is nailed. The main girders are made serviceable as parapets by the addition of twisted wire ropes, as indicated by the dotted lines. The weight of iron and steel would be about 12 tons. Foot-bridges, with the roadway on the lower part of the structure, are often made with bow-string girders, but the parallel girders can be more conveniently held at the ends.



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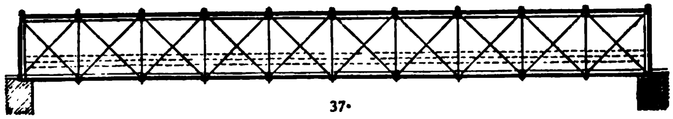

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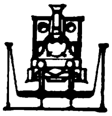

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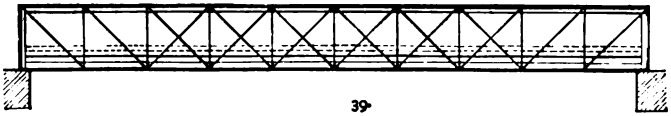


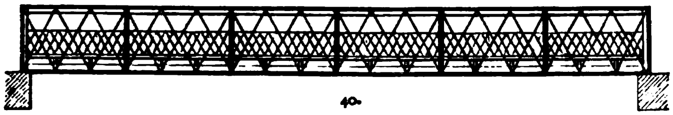
39.

Single-line railway bridge.

Example N.—A bridge 100 ft. span and 14 ft. wide for carrying a single line of standard-gauge railway equal to a moving load of $1\frac{1}{2}$ tons per lineal foot. The bridge is formed of two main girders 10 ft. deep, and steel cross-girders. The rails are carried on longitudinal steel bearers attached to the cross-girders, which also sustain a complete deck of planking. There is wire-rope railing, as in M. The weight of iron and steel would be about 37 tons.

Highway bridge 18 ft. wide.

Example O.—A bridge 100 ft. span and 18 ft. wide, for carrying highway traffic equal to a moving load of 80 lbs. per square foot, or a vehicle with 5 tons on each pair of wheels. The bridge is formed of two main girders 10 ft. deep, lattice-work being added to serve as a parapet railing. The roadway is formed of longitudinal planking laid upon steel cross-girders, and there is an upper layer of wearing planks placed transversely. The weight of steelwork would be about 36 tons. There is little difference in weight between this bridge and Example D, as the cross-girders, though longer in span, have not a heavy weight to carry, and there is therefore little scope for saving weight.



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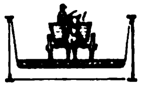
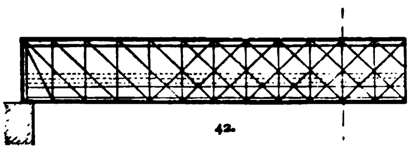


41.

Double-line railway bridge.

Example P.—A bridge of 100 ft. span and 26 ft. wide, for carrying a double line of standard-gauge railway equal to a moving load of 3 tons per lineal foot. The bridge is formed of two main girders 10 ft. deep, and a platform is made of cross-girders placed 10 ft. apart, longitudinal rail-bearers, and planking, as in Example N. The weight of iron and steel would be about 80 tons.



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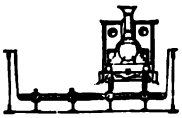
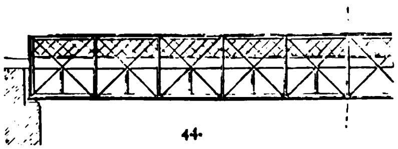


43.

Highway bridge 30 ft. wide.

Example Q.—A bridge 100 ft. span and 30 ft. wide, for carrying highway traffic equal to a moving load of 80 lbs. per square foot, or 8 tons on a pair of wheels; the width allowing for a carriage-way of 20 ft., and two footpaths of 5 ft. The bridge is formed of two main girders 10 ft. deep, and cross-girders placed 5 ft. apart. The platform is composed of planks 6 in. thick, laid longitudinally on the cross-girders, and wood roadway blocks 4 in. thick are bedded in asphalte on the planking. If 2 ft. 6 in. (one-twelfth of their length) were allowed for the depth of the cross-girders, and 1 ft. 6 in. for the thickness of road material, including packing and curbs, the main girders would still be left as parapets 6 ft. high above the road level. As, however, in a highway bridge it is more convenient to have a parapet of moderate height, that is to say, 4 ft. instead of 6 ft., advantage may be taken of this circumstance (if the levels or gradients of the approaches in their relation to the headway below allow it) to make the cross-girders deeper, and by such an economical application of material to reduce their weight. A depth as great even as one-fifth of the span may be given to the cross-girders; but in the present case they are made 4 ft. 6 in. deep, and the parapet is only 4 ft. high. The steel and ironwork would weigh about 52 tons.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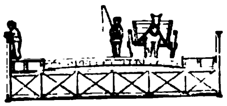
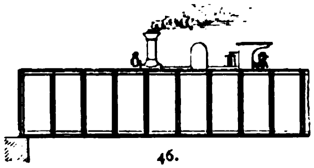

45.

Railway bridge for four lines.

Example R.—A bridge 100 ft. span and 52 ft. wide, for carrying four lines of standard-gauge railway equal to a moving load of 6 tons per lineal foot. The bridge is formed of three plate main girders 10 ft. deep, the centre one having double the strength of the outer girders. The platform is formed of cross-girders, longitudinal bearers, and buckled plates. Asphalte ½ in. thick and ballast 12 in. thick are laid upon the plates, and the rails are attached to longitudinal or cross sleepers, according to the system of permanent way in use on the railway, this method being preferred by many engineers. The plates, ballast, sleepers, and rails would together impose a weight of about 140 lbs. per square foot on the bridge. The steelwork would weigh about 235 tons.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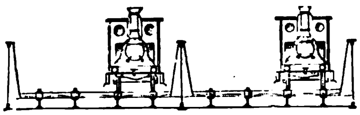

47.

For Prices, *See page* 154.

A bridge with a wide roadway constructed in this way compares favourably in weight and cost with one in which only two main girders are employed, as cross-girders spanning the whole width of the platform, without intermediate support, would be heavy and expensive. Or, as already described in Example F, instead of one strong central girder, two girders similar to the outer ones may be employed. Highway bridges are not so often made with central girders in this way, because a raised girder in the centre of the road is objectionable, except in cases where it can be utilised for dividing the lines of traffic. But where owing to the levels of the approaches and the amount of headway required below the bridge, cross-girders spanning the whole width would by their depth so raise the height of the platform as to render the gradient of the approaches excessive, intermediate main girders become necessary to allow of short and shallow cross-girders, thus dividing the roadway into avenues, the ends of the central girder being protected by guard-posts and lamps. In a bridge with a narrow carriage-way, the span of the cross-girders may be kept sufficiently short with only two main girders by carrying the footpaths on brackets outside the girders, thus leaving the carriage-way undivided.

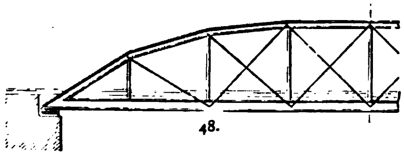
Intermediate girders objectionable for highway bridges.

The following Example shows deep riveted girders of a kind sometimes employed.

Double-line railway bridge.

Deep girders.

Example S.—A bridge 100 ft. span and 26 ft. wide, for carrying a double line of standard-gauge railway equal to a moving load of 3 tons per lineal foot. The bridge is formed of two steel main girders 14 ft. deep of the bowstring kind, this name being given to girders with a curved upper flange and a horizontal tension member. In the present case the upper member is polygonal, as allowing a cheaper application of the steel than if it had to be cut or bent to a curve. Under most conditions of loading, girders of this shape can be made with less material than parallel girders, but where the loads to be carried are light, there is little if any economy in practice. The depth of the main girders also allows a reduction in the weight. Cross-girders are placed 13 ft. apart; there are also longitudinal rail-bearers, and the platform is made as in Examples N and P. The steelwork would weigh about 78 tons.



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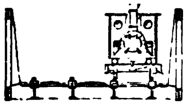


49.

Referring to the summary remarks on page 157, concerning Examples A to F, it may now be observed that Examples M to R are alike in having riveted girders of the trellis or lattice kind; in having a depth one-tenth of the span; and in having the roadway on the lower part of the structure. Girders deeper than one-tenth allow, as has already been said, a slight saving in weight; but in the case of bridges like those which have just been described, such girders to be effective must be deep enough to allow overhead bracing without obstructing the roadway. But except in bridges of moderate width, the distance to be spanned by the overhead bracing renders its use difficult or practically impossible; and if deep girders are made without overhead bracing, the expense and inconvenience of stiffening them in some other way greatly reduces the saving otherwise obtained. A headway of from 14 ft. to 16 ft. is generally considered necessary for the passage of loaded vehicles; a locomotive of standard gauge measures about 13 ft. 6 in. to the top of the funnel; a passenger tramcar measures from 10 to 11 ft. from the ground to the top rail of the roof, and for outside passengers standing up on such a car, 16 ft. would be necessary. The Board of Trade regulations for bridges in England prescribe a headway of 16 ft. for highway traffic under railway bridges. But for overhead bracing on highway bridges, conditions of headway may be, and frequently are, relaxed, and where a clear headway of 14 ft. is afforded, overhead bracing may generally be permitted. Trussed girders on the pin system, which may be made as deep as one-eighth or even one-fifth of the span, afford then a height for overhead bracing in spans less than 100 ft.

Overhead bracing for deep girders.

Headway necessary below bracing.

See TRAMCARS, *page* 309.

The necessity for girders shallower than one-tenth of the span does not arise in the present category of bridges in the same way as with those previously described, since it may be assumed that there is unlimited space above the platform of a bridge. But deep girders are often considered unsightly; they may obstruct light and air; and they present a great surface to the wind. In cases where considerations such as these prevail, a depth of less than one-tenth may be adopted. In some situations there is a special liability to wind pressure, and since the catastrophe of the Tay Bridge this liability has received more attention than formerly. Although in countries subject to cyclones and violent hurricanes the extraordinary horizontal pressure of 100 lbs. per superficial foot may have been registered, such forces are concentrated on small areas, and 50 lbs. per foot would be enough to allow for the whole side surface of a

Deep girders sometimes objectionable.

See EXAMPLES H & J, *page* 159.

Wind pressure.

Cyclones.

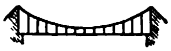
large bridge structure even in exposed situations, while 40 lbs. is sufficient in Europe and in moderate climates.

See page 137.

As Arched bridges have been cited as the kind which allow the minimum depths of parts below the platform in the centre of the span, so, in the present category, Suspension bridges might be said to allow the minimum height of structure above the roadway in the centre of the span.

Suspension bridges.

In the foregoing examples the span of 100 ft. has excluded Suspension bridges, which are seldom used for spans less than 100 ft.; and the advantages they afford—except sometimes for very light foot-bridges, or when the difficulties in erecting a girder bridge are very great—commence generally only when a span of 200 ft. is reached. As an arched bridge depends for its stability on its abutments, so a suspension bridge depends on the anchorage of its chains; and the suitability in this respect of the site and available building materials greatly determines the cost or expediency of such a bridge. The ordinary suspension bridge, in which the platform is suspended from a catenary chain, is necessarily less rigid than a girder or arched bridge, and while the undulatory movement under moving loads of a platform thus suspended does not render it unsafe for ordinary highway traffic, it makes such bridges unsuited for the passage of railway trains, except in the case of very long spans—over 1,000 ft., where the great weight of the structure gives a stability less susceptible to the impact of such a load as a railway train; and with some additional stiffening a suspension bridge of more than 1,000 ft. span, if strong enough for highway traffic, would carry a railway also. But there have been various improvements in suspension bridges, mainly in the direction of increased rigidity, and, by the combination of other systems of construction, suspension bridges may be designed rigid enough for railway traffic. Suspension bridges can be erected from the shores of a river or ravine without the need for temporary staging or any other intermediary support from below; and it is by the facilities afforded in this respect rather than by any economy in the cost of the structure itself, which in very many cases justify the choice of a suspension bridge rather than a girder bridge.



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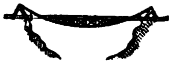
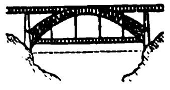
Suspension bridges for railways.



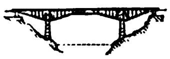
51.

Since the year 1875 there has been a great development of Cantilever bridge construction which allows of erection over wide and deep rivers or ravines without temporary staging. The bridge over the Douro at Oporto crosses the river where rocky abutments favour the use of an arched structure. The bridge has a total length



52.

of 1278 ft. with a central span of 566 ft., there being both a high level and a low level roadway. The arch, whose crown is 204 ft. above water, was projected forward from each shore, the segments being held by temporary suspension cables till the arch was completed. The Niagara Bridge (52) has a central span of 315 ft. with a height of 125 ft. above the water, and was built forward without staging. The Blau Kranz Bridge in South Africa (53) has a central span of 250 ft., the pier-legs being much wider apart at their base than at the top, the structure being built forward by the aid of wire rope stays and temporary suspension. The Forth Bridge, in Scotland, built in 1883–9, has two spans of 1,700 ft., and the cantilevers were built forward on either side of the towers so as to balance each other. In all these cases steel wire rope was extensively used, and it is questionable if any of the bridges above named could have been erected without its aid. But while the cantilever has been adopted for facility in erection, the arch which can also be built temporarily as a pair of cantilevers would in many cases form the best permanent structure. There are various combinations which may be adopted to meet particular cases, such as the girder and arch or the girder and suspension. Such designs can seldom be repeated, as there are generally circumstances which render special treatment necessary, and it is only for small spans that the designs of previous bridges are exactly applicable.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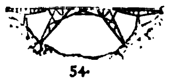
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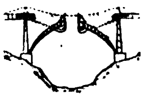

55.

Bridges objected to.

Difficulties of access.

Before concluding this chapter on bridges by enumerating the particulars of purpose and locality which must be held in view by the engineer or contractor in preparing a design or estimate, the alternatives may be considered which are available when the objections to a bridge cannot be overcome at reasonable cost. For there may be difficulties of access or of construction which appear to render a bridge impossible, and there are also to be dealt with the obstructions which an ordinary bridge presents to the navigation of a river. Dealing first with the difficulties of access, where a bridge replaces an older structure or follows the line of a ford or ferry the existing approaches are generally available with or without an alteration of the levels, but where an entirely new crossing is projected the rectification of neighbouring roads or streets may become very expensive. Indeed, in a city the purchase of land for the approaches, or of riverside wharfs, or the compensation for rights invaded, in short "the right of way" is sometimes more costly than the bridge

Approaches.

Purchase of land.

Right of way.

itself. In such cases it is of course desirable to utilise the right so acquired to the utmost. One way of effecting this is to make the approach and the bridge itself wide enough for a railway as well as a road. But, generally, the levels of the two do not accord, and to meet this the bridge may be constructed with two decks, one, generally the highest, for a railway, and the other for a highway, as at Newcastle over the Tyne, at Cologne over the Rhine, or the Brooklyn suspension bridge, or the arch bridge over the Mississippi at St. Louis. Or even where both decks are not wanted at first the main parts of the structure may be made strong enough for receiving the second deck afterwards, as referred to below in the Tower Bridge. On the Forth bridge again, it would have added but slightly to the cost to have provided a low level deck for highway traffic, which, when it is added hereafter, may involve greater expense and uncouth alterations or additions to the structure. The local authorities may, in the case of railway bridges where no contiguous bridge is available, at any rate demand with advantage the provision of footpaths fenced off from the railway tracks.

Two-decked bridges.

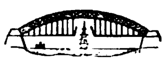
Examples.

Objections to fixed bridges.

The objections to a fixed bridge over a river because of the obstruction it presents to the passage of masted vessels may sometimes be met by providing an Opening span in the bridge, or by having a Bridge of Boats or by the construction of a Subaqueous Tunnel. Taking these alternatives in their order—

Opening bridges.

Opening bridges are often required to allow the passage of masted vessels, and sometimes they are provided to meet the demands of local authorities or river conservators, even where only a remote future necessity is the reason. The opening part may revolve horizontally, or may lift vertically as a bascule bridge. Opening spans may be made most easily in girder bridges, as when made in an arch bridge, the pier which is isolated from the shore while the bridge is open has to be made strong enough as an abutment to withstand the lateral pressure of the arches. But where it is important to avoid intermediate piers, an opening can be made in the platform of an arched bridge of one span, without breaking the continuity of the arch. This plan was proposed in 1885 by the Author for a bridge over the Thames at the Tower in one span of 850 ft., to avoid the wide piers which in the bridge as actually built obstruct the waterway. By launching forward from each shore one half of the arch, such a bridge can be built without the obstruction of



56.

temporary staging. And if, at a future time, the opening in the bridge be no longer required, no piers are left in the river. Further, by making the arches strong enough at the outset, an upper platform may be added in the future, when the non-use of the centre opening renders the addition of a high-level railway bridge possible and desirable, and the railway approaches could also then be constructed over the street approaches without the acquisition of a new right of way. In a suspension bridge an opening for the passage of vessels can be made in the tower, but such openings are expensive, and are to be avoided when possible. When bridges have to be opened frequently (as is the case at the entrance to a dock), the apparatus must allow rapid movement, and the modern system of hydraulic machinery is that most usually adopted for the purpose.

Hydraulic opening apparatus. *See page 493.*

Floating bridges.

Floating bridges are often needed where the water is too deep for bridge piers, or where the occasional opening of the bridge for the passage of vessels can be much more cheaply effected in a bridge of boats or pontoons than in an ordinary bridge. The bridge of boats at the Golden Horn, Constantinople, that across the Hooghly at Calcutta, that across the Danube at Vienna, and the bridge across the Neva at St. Petersburg are examples. In all these, openings for the passage of vessels have occasionally to be made, and in the two latter the bridge may be entirely removed during seasons of ice. Flat-bottomed pontoons made of iron or steel plates are generally used for permanent floating bridges.

Examples of boat bridges.

Pontoons.

Design and cost, how determined.

The points special to floating bridges as determining their feasibility, design and cost, are the depth of water, the nature and suitability of the ground for anchorage, the direction and strength of the current or tides, the occurrence of heavy winds or storms, and the liability to collision from vessels, rafts, or floating ice.

Subaqueous tunnels.

Subaqueous tunnels may have to be considered where the construction of any kind of bridge is hindered because of vested interests in the free passage of masted vessels. Such a difficulty may arise where it is proposed to place a bridge lower down stream than any existing bridge which, from its position, is generally the most important crossing place. It was this difficulty that so long hindered the construction of a bridge below London Bridge on the Thames, and which later so prevented the building of a bridge at Blackwall on the Thames, where, therefore, a tunnel has been substituted. Or the cheaper cost of a tunnel may, in certain cases, be the circumstance which makes it preferable to the bridge, as for instance where deep water, or water subject to storms, may render the construction of bridge piers difficult.

Where preferred to bridges.

Subaqueous tunnels have been numerous enough to afford considerable data regarding the feasibility and cost of such undertakings. The Thames tunnel by Sir M. I. Brunel (1825–43) is 1200 feet long, affords two passage ways, each 15 feet 4 inches high and 13 feet 9 inches wide, the excavated cross-section enclosing them being 22 feet 6 inches high and 38 feet wide. To minimise the depth and allow convenient access, the tunnel was made so immediately under the river bed, there composed of gravel and mud, that, notwithstanding the protection of a moving shield, there were two irruptions of the river during the progress of the work involving loss of life. As the only access was by spiral staircases in the vertical shafts, the tunnel was available only for foot passengers, and altogether failed to realise the anticipations concerning it. But in later years the tunnel has been utilised for the East London Railway, which approaches through long cuttings between lofty retaining walls, and by a tunnel under the adjoining London Docks, a passenger station being provided at each end at the old entrance shafts.

Brunel's Thames Tunnel.

How constructed.

Railway in Thames Tunnel.

Below the silt and gravel bed of the Thames is the stratum known geologically as the London clay, which affords great facilities for subaqueous tunnelling, as was first proved at the Tower Subway (1869–70) for foot-passengers about half a mile from London Bridge, where a bridge crossing was forbidden as an obstruction to passing vessels. This tunnel, which was made of cast-iron segmental rings, is 7 feet in diameter and 1350 feet long, and the ease with which it was constructed, without compressed air or diving apparatus of any kind, led the way to further similar works in London.

London clay stratum.

Tower Subway.

The City and South London Railway (1886–90), almost all in tunnel through the London clay, passes under the Thames a few yards above London Bridge, the line being taken under the river bed for about 1200 feet in two tunnels, each 11 feet diameter, lined with iron. Following this, the Waterloo and City Tunnel (1894–6) was constructed under the Thames through a similar stratum, and with the same facility. As in all these cases passenger traffic only was concerned, access at each end of the tunnel was easily arranged by ordinary hydraulic elevators or lifts. The general success of this system led the way to the construction of the Central London Railway

Tunnel for South London Railway.

Central London Railway. (1896–8), which is, for most of its length, through the London clay at a depth of from 50 to 70 feet below the streets. In this case the object of tunnelling deep below the surface was to excavate so far below buildings and foundations as to avoid compensation for property, unless actual damage was proved. As a condition for such immunity the tunnel is lined throughout with cast-iron.

But other sub-aqueous tunnels have been made where the strata pierced have not been so favourable as the London clay. The tunnel under the Severn (1882–6) is 26 feet wide, for a double line of railway, and 7942 yards long, half of which distance is under the tideway. The main difficulties arose from fresh-water springs not connected with the Severn water above. The Mersey Railway Tunnel (1880–6) between Liverpool and Birkenhead is about two miles long, and passes through sandstone under the river, where it is 1320 yards wide. For about 500 yards in the middle the tunnel is nearly level, but the approach gradients vary from 1 in 27 to 1 in 36. The arched section of the tunnel is 26 feet wide, and 21 feet high. At the stations adjoining the river access is obtained by hydraulic elevators.

Severn Tunnel.

Mersey Tunnel.

Clyde Tunnel. The passage-way under the Clyde at Glasgow, completed in 1894, is composed of three tunnels 17 feet diameter, the centre one for foot passengers with inclined approaches, and the outer ones with hydraulic lifts for vehicles.

Albert Dock Tunnel. The tunnel, 1800 feet long, under the Albert Dock, London, was built (1879–80) in open cutting (while the dock was being constructed) to carry the double line of the North Woolwich Railway, which for some years previously had traversed on the surface level the space afterwards excavated for the dock. The rail level is 43 feet below high water level; the roof of the tunnel is 4 feet 6 inches thick of brickwork in cement mortar, and there is a depth of 25 feet of water in the dock above the tunnel. The line, as relaid in the tunnel, was connected to the railway on the surface by gradients of 1 in 50. After completion the water was admitted to the dock and the tunnel submerged.

Hudson River Tunnel. The tunnel under the Hudson River at New York as projected, was 5400 feet long from shaft to shaft, and consists of two single line tunnels each 18 feet high and 16 feet diameter, lined with a casing of wrought-iron plates. To minimise the gradients of the approaches, the river bed was pierced so closely below the waterway through strata of mud and silt, that somewhat the same difficulties were encountered as at Brunel's Thames Tunnel. By the use of compressed air an ingenious shield was moved forward as the tunnel was excavated, and lined with iron segments as the work proceeded. More than half the length of the tunnel was successfully constructed before 1891, when it was abandoned for want of funds. The feasibility of the plan adopted was, however, confirmed by its application, with considerable improvements, to the tunnel under the Thames at Blackwall, of which 1212 feet is under the river bed, constructed in the years 1892–7, through strata very similar to that of the Hudson. Here, again, in order to minimise the approach gradients, the tunnel is immediately under the river bed, and the difficulties of keeping out the water by air pressure were increased by the continually varying head of water, as the tide rose and fell within a range of about 17 feet. Although this tunnel was successfully completed under special difficulties, the choice of a tunnel instead of a bridge may be deemed a mistake. The approaches on either shore are through expensive cuttings, with severe gradients of 1 in 34, limiting the load which horses can draw. Owing to the exigencies of construction under air pressure, the tunnel has a width of only 27 feet, which though wide for a tunnel, is narrow as a highway. The tunnel cost from £105 to £126 per lineal foot according to the lining, and the "cut and cover" portion from £60 to £90 per foot. A bridge was deemed impracticable because of the headway required for masted vessels, and a bridge sufficiently lofty would have involved long and expensive approach viaducts, with gradients as steep as those required for the tunnel. This difficulty could have been met at half the cost of the tunnel by a single-span arch bridge, with a wide roadway and with moving platforms for raising and lowering the traffic, thus affording the great advantages of level approaches. The feasibility of such moving platforms has been proved by many examples on a small scale, and the cost of working them would be less than that of the labour expended in hauling the traffic by horses up the gradients from the tunnel.

Compressed air tunnelling. *See page* 501.

Blackwall Tunnel.

Difficulties of construction.

Bridge and tunnel compared.

Bridge deemed impracticable.

High-level bridge.

Moving platform.

The subway or conduit 4 miles long under Lake Michigan for the water supply of Chicago, is another example of subaqueous tunnelling, as also is the tunnel, 6000 feet long, under the St. Clair River (1888–90) for the Grand Trunk Railway of Canada. This tunnel is 21 feet diameter, lined with cast iron, and was the first on a large scale completed by means of a shield and compressed air. The ground consisted for the most part of soft clay, with occasional

Lake Michigan Tunnel.

St. Clair River Tunnel.

pockets of gravel and sand. The heroic project of a submarine tunnel between Dover and Calais is certainly feasible, and is only hindered by political reasons.

Information necessary to design a bridge.

To enable an engineer to design a bridge which will best fulfil the purpose in view—to satisfy at the same time the varying exigencies of transport, site, and climate, and to allow a contractor to estimate correctly the cost—information of the kind described on the following pages is necessary. It will be seen that the particulars enumerated include those for a great variety of cases, and those applicable to any particular case must be selected accordingly. Moreover, as many of the particulars are necessary only to the design, these may be omitted where it is intended only to furnish a contractor with information sufficient for estimating the cost of erecting in its place a structure which is already designed.

Plan of site.

1. A plan of the *Site* showing the position of the bridge in relation to the river (or other space to be crossed) and the approaches, and whether the bridge is to cross at a right or a skew angle. If the number and length of spans have been determined, the positions which have been selected or which appear most favourable for the piers and abutments, should be indicated.

Cross-section showing levels.

2. A cross-section of the site, showing the *Level* of the roadway of the proposed bridge; that of the approaches; and also that of the river, road, ravine, or railway, which the bridge is to cross. If a river, the various levels of tide or flood should be marked, so as to indicate the headway available at different seasons below the bridge. These circumstances determine largely what system of superstructure can be applied, and to gain sufficient headway it sometimes becomes expedient to raise the bridge to a higher level than that otherwise necessary, and this may involve steep gradients in the approaches or long and expensive approaches to obtain easy gradients. The designer—if free scope be not allowed him in these respects—must be informed of the maximum gradients which will be allowed on the bridge and approaches.

See page 137.

Gradients on approaches.

3. If *Piers* or abutments have to be built, the nature of the ground must be stated, and this can be conveniently done upon the cross-section referred to above, which should include also a profile of the river-bed from shore to shore, showing the slope of the banks and the various strata down to a firm foundation. If the strata are not known with sufficient certainty from previous experience, or from trust-

Nature of the river-bed and banks.

worthy borings in the neighbourhood, it will be necessary to ascertain the facts correctly by making trial borings in the river-bed, or approximately by driving bars or piles into the ground and noting the number and force of the blows necessary to pierce a certain depth. The cost of such investigations will be always amply repaid by the help they afford to the designer, who can only, when thus informed, make the supports of the bridge of a suitable form and strength. Moreover, having thus entertained the kind and probable cost of the foundations, he can weigh the advantages of numerous piers and short spans against the opposite advantages of few piers and long spans. In connection with the foregoing particulars, the strength and direction of the water current should be described, and, if the river be navigable, the nature of the boats or vessels, including the heights of their masts, which will pass below the bridge. Mention should also be made of any floating trees or ice which the piers and abutments may have to withstand, and as to how far, in time of flood, such obstructions might reach up to the superstructure.

Strata proved by borings.

Passage of vessels.

Floating trees or ice.

Too often when the information is furnished to the engineer from a distance, the particulars supplied on these points are so meagre that he is unable to make the most appropriate design, and not daring to run risks which an assumption of unknown facts would involve, gives an unnecessary strength and margin of safety to the supports. A mere statement that the bed of the river is sand, mud, or rock is not sufficient, unless the firmness and depth of the stratum be also described, for these facts alone can determine not only the kind of supports but the depth to which they must penetrate, and the area of base necessary. Sometimes no information whatever is furnished on these points, but a mere direction only is given that the bridge is to be supported on cylinders or screw-piles, although it should be obvious that the form of screw-piles, or of any other supports, and their length from the superstructure downwards, will depend entirely on such particulars. Even where one span only is required, and where no piers or abutments have to be built, information in regard to the suitability of the river-bed for pile-driving should be stated, if staging is to be employed for the erection of the superstructure.

Information often too meagre concerning foundations.

Pile-driving.
See PILE-DRIVERS, *page* 845.

4. The *Load* which the bridge is to sustain, and the margin of safety required, should be given. If a railway bridge, either a prescribed load per lineal foot should be stated, or a description given of the heaviest locomotive likely to run on the line, including its weight, extreme length, length of wheel-base, and maximum weight

Prescribed loads.

See pages 149 *&* 697.

Description of vehicles. *See page* 148.

Opening bridges.

on any one pair of wheels. If a highway bridge, the kind and frequency of the traffic, and such a description of the heaviest loads that must be provided for, that the weight concentrated on a pair of wheels, or on a wheel-base of certain area, may be calculated. If openings are required in a bridge to allow the passage of vessels, the kind and maximum size of vessel should be stated, and also whether the vessels may be expected to pass frequently or rarely. By this latter circumstance the kind of opening apparatus will be largely determined.

Exigencies of transport.

Erection on site. *See also page* 135.

Local information. *See also page* 74.

5. The exigencies of *Transport* which may require the division of a bridge structure into pieces of a certain size and weight; the special circumstance which may render easy or difficult the erection on the site; the kind of workmen who are obtainable; the building materials available and their prices—must all be sufficiently described. In regard to timber, its kind must be described, so that its suitability for staging and decking may be known.

Minor circumstances.

6. There are other and minor circumstances which also affect the cost of a bridge, and concerning which sufficient particulars must be furnished to the designer. Such, for instance, are the degree of ornamentation desired; whether parapets or only mere railing is required; whether lamps are necessary; whether side-walks are wanted, and if so their width; and whether provision is to be made for taking water or gas mains over the bridge.

Terms of concession. *See page* 134 *and also Chap. II.*

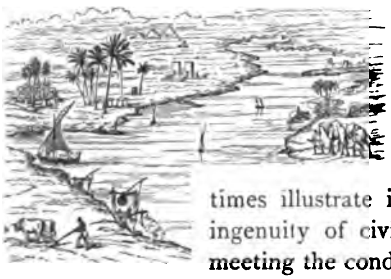
Official tests.

7. If a bridge is to be erected in virtue of a concession, the terms and conditions must be fully set forth and the right-of-way affirmed. If the *Payment* is to depend in any way upon a revenue from tolls, the calculations of expenditure and revenue, and the data upon which they have been based, must be furnished. If the bridge has to satisfy some specification of quality, or be officially inspected, the standard of quality or the nature of the tests should be described; and also whether the material is to be subjected to trials, and, if so, their nature; or whether a certain kind or brand of iron or steel, or guarantee of quality will be sufficient.

[*See also* LANDING-PIERS: IRON AND STEEL DIVING APPARATUS: PORTLAND CEMENT.]

CHAPTER VIII.

IRRIGATION. RECLAMATION OF LAND.



Ancient works.

Investigation of ancient methods.

If public works were classed in order according to their antiquity, those of Irrigation would justly hold one of the first places. The systems of irrigation adopted in ancient times illustrate in a very striking manner the ingenuity of civilised or half-civilised races in meeting the conditions of soil and climate under which they lived; but besides the interest naturally excited by such ancient works, much valuable information is afforded by them even to the modern engineer, who may, for instance, investigate with advantage the extent of surface irrigated from certain sources of supply; the amount of animal or other power that must have been expended in raising water to irrigate a certain breadth of land, and the periods during which such works have remained in an effective condition. It is also interesting to examine the modes by which irrigation works were rendered financially successful under conditions apparently so insecure that at the present time they would forbid the investments of labour and money; and also the reason why such works may have failed.

Irrigation works defined.

Local irrigation

Irrigation works comprise the collection, control, distribution, and application of large quantities of water; the best and most economical methods having to be determined under conditions that vary in every locality. Local irrigation on a small scale is a matter rather for the agriculturist than the engineer, and in all but the most uncivilised countries advantage is taken of adjacent water supplies by owners or occupiers of land. Even in small works of this sort there are different systems, depending on the nature of the supply, the contour of the ground, and the kind of crops. An English water-meadow, a Swiss valley, and an Indian rice-field afford examples of local irrigation still conducted according to the traditional methods in use centuries ago. It is, however, where large works are required —where water has to be brought from distances, pumps erected, rivers embanked, canals or acqueducts constructed, and water stored—that the assistance of the engineer is called for. The difficulties which have been overcome, and the problems which have been solved, in connection with important irrigation schemes of this description, are among the most conspicuous examples of successful engineering enterprise.

Large works.

The designing of irrigation works depends on natural and local circumstances as much as, if not more than, any other branch of engineering, and for this reason personal inquiry and examination of the fullest kind must be made on the spot by the engineer. The engineers who can best carry out these works should not only have personal experience of previous works, but be acquainted with what has been done by others under various conditions. Experience of hydraulic works is particularly necessary, and a knowledge of other sciences—such as meteorology, geology, agriculture, and even chemistry—is also wanted; though information on these points from those locally and technically conversant with what is necessary to produce certain results on land and crops, may make available the engineer's special professional skill.

Special skill required.

The principal irrigation works of modern times have been mostly confined to warm climates, such as those of Egypt, India, China, Ceylon, Jamaica, California, Italy, Spain, Portugal, and the South of France. Accounts of these works, comprising what may be called the literature of irrigation, are available for reference but not always in a convenient form, being often partial and incomplete, and contained in a large number of books, few of which are written in the English language. Not the least useful are the bare records of facts, and the statistics of particular works which have been published in different countries under Government or other official sanction.

Examples of important works.

Classification of systems.

Irrigation works do not admit of any rigid system of classification; they may, however, be broadly classed in several ways.

Classification A, according to whether they require the aid of mechanical appliances on a large scale—for instance, where steam, animal, water, or wind power are necessary—as distinct from those which depend on gravitation alone.

Classification B, according to whether they do or do not involve works of storage to any great degree.

Classification C, according to the nature of the irrigation to be effected.

In Classification C. irrigation schemes may be said to consist of *three* kinds, which, however, cannot be considered as wholly distinct. The first is *Occasional* irrigation, having for its object a sufficient supply of moisture to the crop under cultivation and the softening of the surface of the soil to facilitate tillage—a method principally adopted in hot and arid countries, and more temperate climates during periods of summer heat and drought. Thus in India in many districts the land must be softened for ploughing, and as the period for this is before the rainy season, irrigation becomes necessary; the after rains fertilising the seed. The second is *Sedimentary* irrigation, which has for its object the fertilisation and improvement of the cultivated soil by the application to it, in a stream more or less continuous, of the natural sediment and the dissolved matters contained in the water, which itself may be assumed to act as little more than a vehicle for carrying and depositing the sediment. This kind of irrigation includes that of rice fields in India and China; the flooding irrigation of Egypt, in which the Nile sediment acts so important a part; the *marcite* and *prairies permanentes* irrigation of Italy; and the water-meadow irrigation of England and other cold and temperate climates. Even where rain is plentiful, the cultivator will often allow the rain-water to run off, preferring the artificial supply for the sake of its fertilising properties. The third is *Sewage* irrigation, in which the fertilisation of the soil is effected by manure, the water both acting as a vehicle and as a diluent; the objects being in most cases both the riddance of noxious refuse from towns and the securing an increased yield from the soil thus improved. This mode of irrigation has been principally confined to cold and temperate climates.

Simple irrigation.

Sedimentary irrigation.

Sewage irrigation.

Town drainage. *See page* 208.

While, then, these three modes of irrigation are perfectly distinct in most cases—the choice being determined by circumstances that may demand one to the almost entire exclusion of the other two—there is no reason why they should not all be employed to an important extent in the same scheme. There are many schemes of a combined description in which irrigation is only one of the objects, and sometimes a very subsidiary one. This may be the case when navigation either in the canal of supply, or in the river constituting its source, is of importance; but it is a vexed question how far irrigation and navigation by the same canal can be

Different systems combined.

Irrigation by navigable canals.

ever rendered profitable. There are also cases where the question of protection from floods, general drainage, river improvement, land reclamation, or town water-supply, complicate the conditions of the design. When such combinations occur as not only render the irrigation quite subsidiary, but compromise its efficiency and regularity to any great extent, the irrigation profits become very much reduced.

Subsidiary works.

It is necessary in an irrigation scheme to provide not only for supplying the water, but for the disposal of the surplus water. Drainage questions will almost always arise, and should therefore form part of the project from the first.

Drainage of surplus water.

Sources of profits.

The two sources of return from investments in works of irrigation are, the increased amount of produce and the enhanced value of the land; and it is these that alone can repay all concerned in the undertaking, from the field-labourer on the spot to the investing capitalist at a distance. There are, besides, considerable benefits not directly affecting either the cultivator, the landed proprietor, or the capitalist, which result from the utilisation in trade and commerce of the larger amount of money and produce brought into public use. The local, and sometimes even the national, prosperity due to the impetus thus given by extensive irrigation works is an important advantage, independent of the direct return previously mentioned. The newly-developed trade supports and creates a new population, and taxation then yields an increased revenue to the State. Some of the irrigation schemes promoted and guaranteed by the Government of India can only be justified economically by the indirect advantages they promise, and they have already in many cases fully answered expectations. For instance, in Orissa (India), the development of the country, as shown by the yield from taxation, has been considerable, and the export trade in rice and other seeds has even created a new port. It is for these reasons that national and local governments are enabled to assist such projects by suitable guarantees and concessions; but when once the results of such schemes have been made manifest in practice, it becomes questionable whether concessions or guarantees are any longer expedient, and whether the outlay for new schemes should not be made directly from public revenues, or left entirely to private capitalists without guarantee.

Indirect benefits.

National advantages.

Trade and revenue promoted.

Concessions and guarantees.

See Chapters II. and III.

See page 34.

A well designed project of irrigation, carefully executed, will, if well managed after it is established, repay its cost by means of its combined direct and indirect benefits. Instead of mere patronage and philanthropic assistance, schemes of irrigation require rather a clear-sighted, thorough examination of all the points affecting them in the first instance, and a persistent adherence to correct principles in their execution, development, and management afterwards. Hence the necessity for able and well-qualified men both in the engineering and in the administrative superintendence of works of this class, and for enterprising and skilful landowners and farmers, who will develop to the fullest extent the improved agriculture rendered possible by irrigation. Irrigation pays best—other conditions being equal—where there is an agricultural population sufficiently large to do full justice to the improved land, and where also they have or can borrow capital for utilising the water. Thus the irrigation of rice-fields in some parts of India has been profitable because there is a large population devoted to agriculture, and who look to it for their livelihood without any thought of changing their position. On the other hand, irrigation works executed in sparsely-peopled districts, in the hope that the advantages afforded would bring the surplus population from less favoured districts, have failed, because of the unwillingness of the people to leave their accustomed homes, or because they have not the means to utilise the advantages offered to them. In such cases profits cannot be looked for in the first years, and government or other guarantees are necessary for a limited period.

Conditions of success.

Able administrators necessary.

Large population advantageous.

There is nothing which suffers so much from neglect as irrigation works, as the ancient tanks of India, or the arid sides of hills once watered by channels now in ruins, so frequently testify.

Neglected works.

The financial success of an irrigation scheme depends, of course, upon the return which can be obtained from a certain outlay. The outlay consists mainly of the purchase of land, the cost of works, and sometimes of compensation for proprietary rights. To this outlay must be added the engineering and legal expenses, and sometimes also the adaptation of the land. In most cases the proprietors are willing to undertake this adaptation at their own expense, their prospective share of profits enabling them to incur the expense as a charge on their estates, and to raise money privately for the purpose, thus in effect reducing the first cost of the project.

Financial success.

Items of cost.

Adaptation of land.

Capital may be provided in a variety of ways. In some cases, though rarely, the landowners or occupiers subscribe among themselves according to the extent of their holdings; in others the local

Capital—how to be provided.

or national Government provides the money; and in others it is subscribed by outside capitalists. In the two latter cases the landowners or occupiers who directly benefit by the irrigation can pay rent for the water in the shape of a water-rate, calculated according to the amount of water they receive or the area irrigated, or they can resign to the Government or capitalists a certain proportion of their land.

A sound irrigation scheme generally provides not only for a remunerative return, but for the gradual repayment of the capital itself within a stated term, thirty to forty years being a usual time. In order to recover the whole of the capital within this period, the annual water-rate must be determined accordingly, and a sinking fund provided. By estimating the average likely to be irrigated annually, and the supply of water likely to be utilised at various seasons, an appropriate rate either per acre, or per cubic foot per second of supply, suitable to the various kinds of irrigation and descriptions of soil, can be properly fixed. It is, however, evident that the rate must be not only sufficiently high to cover cost, maintenance, and repayment, but also sufficiently low to leave a profit to the landowners or occupiers. To estimate this, the data enumerated in clauses 6 to 13, on pages 185 and 186, become necessary. If, for example, the non-irrigated land yields £10 per acre clear, and the irrigated land £17, and if the appropriate water-rate determined by the exigencies of the works in the manner already described averages £3 per acre, the profit left to the proprietors or occupiers of the land would then be £4 per acre. If this proportion between the water-rate and the profit prove sufficient and practicable, such a division can be arranged; if not, it may be often necessary to adjust the proportion by arbitration. Unfortunately, however, in many cases the orginal capitalists do not realise any profits, and it is left to later generations to reap the advantages.

Sinking fund. *See page* 39.

Water-rate.

Assessment of water-rate.

Another source of profit is that due to the increased value of the irrigated area after the irrigation has been established, or, after the period of redemption of the capital has expired, where some of the land originally worthless may have become very valuable; an increment from three to tenfold being not infrequent. This prospective enhancement of value does not admit of more than an approximate estimate; but, whatever it may amount to, it may be divided or adjusted between the capitalists of the undertaking and the landowners, in the same manner as the water-rate and the annual profit

Land increased in value.

referred to above. The difficulties which might ultimately attend this division of the prospective increase of value are frequently settled at the outset by the landowners giving a free grant, or a perpetual or long lease of a certain portion of the irrigable area to the capitalists; this plan not only securing to the latter their just share of benefits effected by the works, but giving to both a common interest in the ultimate success of the scheme; while the water-rate is allowed to cover the actual expenses of the undertaking.

Land grants.

It is not safe to rely on the voluntary use of the water supplied by irrigation, as impecunious or conservative agriculturists are often slow to adopt new methods, even when provided for them at reasonable cost. Whatever be the arrangement for the payments, the rate of contribution should be assessed beforehand, and rendered obligatory, either by legislative decrees or by voluntary legal engagements.

Water-rate made obligatory.

In whatever way the redemption of capital and division of profits may be arranged in actual practice, it will be quite evident that no enterprise of this description can prove permanently successful unless every one in connection with it is allowed to obtain his due share of advantage, and unless all claims are protected by sufficient security. In consequence of the great national advantages resulting from successful works of irrigation, previously alluded to as indirect profits, it is generally to the interest of the Government of the country, or the province in which the works are undertaken, to offer facilities or assistance in the form of subsidies, concessions, or guarantees for a limited number of years. In some cases, they defray a portion of the expenses of construction, or give grants of land; in others, they will guarantee a certain interest on the capital expended for a term of years until the irrigation can be sufficiently developed to repay its maintenance; in others, again, they cede proprietary or territorial rights and powers for the recovery of claims. Under any circumstances, and more especially in the case of extensive works, a certain amount of Government sanction is requisite.

Division of profits.

Government aid.
See pages 25-34.

In the case of the land being entirely in the hands of private proprietors who wish to make the matter a local one, it will be necessary for them to co-operate either by supplying a portion of the capital, or by hypothecating or making over a portion of their lands on conditions that will afford sufficient security to those furnishing it. This is the mode so successfully adopted in south-eastern Spain by the Moors, who were masters in this appliance. Many most promising schemes of irrigation fail to attract outside capital, because

Hypothecation of land to capitalist.

Insecurity a cause of failure.

they are projected in countries where legal security is doubtful, and as the returns for irrigation investments are necessarily spread over a considerable period, such lack of security is the most fatal bar to the obtaining of capital. *See page 54.*

Basis for irrigation projects. The information that serves as the basis of an irrigation project is of two kinds, the one comprising the local conditions from an engineering and an agricultural point of view; the other being of a financial and economic nature. Details of the concessions or privileges that will be granted, of the sources from which the works will be paid for, and other information as to the nature of the engagements contemplated, are indispensable portions of any proposal for the construction of works of irrigation.

Information classified. The following list enumerates those particulars to which—some or all of them, according to the nature of the case—an irrigation-engineer on the spot would direct his attention. In countries where there do not happen to be any competent resident engineers, the best method is to collect so much of the information enumerated below as is within the means at command, and to place it before a competent engineer in England, who can advise on the *prima facie* conditions of the case. Some of the particulars enumerated demand the services of a surveyor or engineer accustomed to measuring land and taking levels; others demand geological and meteorological knowledge; while some of the particulars are merely matters of fact which can be ascertained by any person of intelligence in the locality.

Plan and levels. 1. A *Plan* showing the area to be operated on, with the names of the owners and occupiers marked upon it, and a sufficient number of levels referring to a datum.

Sections. 2. A series of *Sections* on all the more important lines, such as the courses of streams of rivers, the water-sheds, the approximate courses of proposed canal and distributaries; also a series of sections over the sites for storage, if these enter into the design.

Natural features. 3. General information as to the natural and *Physical features* of the locality.

Existing works described. 4. A full and detailed account of any *Existing irrigation* works in the neighbourhood, even though they be only on a very small scale; with remarks on the difference of conditions between them and the proposed works; and accounts of any neighbouring navigable canals.

Data for estimating water-supply. *See also page 205.* 5. Data for calculating the amount of natural *Water-supply* available at various points in different seasons; if the source of supply be by one or more rivers, then soundings, showing the water level at various seasons in flood and in drought should be given : a demarcation of the limits of areas submerged at various times : the points at which overflows take place : the periods and duration of floods and droughts : the tendency of the river to deposit silt, and the quality and amount of the latter under different conditions and velocities. Should it be intended to take the supply from wells, full particulars of those already existing should be given as well as regarding the probable depth and copiousness of supply from the proposed new wells, and the geological strata that will most probably be met with in sinking them. Should the storage and collection of surface water, or the interception of streams by dams, be depended on as a source of supply, full information becomes necessary regarding both the geological and meteorological conditions of the catchment area ; this should include all available data of rainfall, evaporation, humidity and absorption. The seasonable occurrence of the rainfall is even more important than a copious supply. In the Orissa famine year (1866) the rainfall was considerably above the average, but it was ill-timed. A description of the superincumbent geological strata, and an account of the mode in which every part of the area is occupied or used, should be furnished.

Floods.

Droughts.

Wells.

Meteorological conditions.

Rainfall.

6. Existing examples of the *Quantity* of *Water* required for watering both in the gross at various seasons over the irrigable area and in detail per acre on various soils ; and the probable effect on the crops of increasing the supply.

Quantity of water required.

7. Full information about the *Irrigable area* itself, its various soils, the crops that are and may be grown on it and anywhere near it, their rotation and probable yield in favourable, average, and unfavourable seasons, and their market value : the systems of tillage in vogue, and the proposed modifications : the trees, shrubs, and plants that are most common, and those growing on the banks of the rivers and near marshes, and the condition of such vegetation, whether thriving or otherwise : the effect on the soil of periodic watering, and long-stagnant water : the climate and meteorological conditions of the area to be irrigated.

Soil, crops, and systems of tillage.

8. The *Soil* in which the proposed works will be carried out ; the stone, lime, clay, brick-earth, and timber available, and their cost ; the kind of *Labour* that can be obtained, and the various rates of wages that prevail.

Materials and labour.
See page 74.

9. The kind and cost of *Fuel* which is obtainable for pumping

Fuel, and power for pumps.

engines; the local opportunities or facilities for pumps to be worked by wind or water power.

Yield of crops per acre.

10. A careful estimate of the value of the average *Yields per acre* of non-irrigated land in the neighbourhood, and, secondly, that of the average yield that irrigated land will produce under the proposed system of rotation, after making allowance for unfavourable years and agricultural contingencies. The number of the population, their habits, and capabilities for utilising irrigated land.

Population. *See page 181.*

Roads, railways, canals.

11. The *Communications*—roads, railways, and canals—by which the produce of the land can be transported; the proximity to markets, and rates of freight by various routes.

Sewage, value of. TOWN DRAINAGE, *See page 209.*

12. If sewage-irrigation is contemplated, the kind, richness, and amount of the *Sewage*, the source of supply, and the terms on which it is to be obtained.

Tenure of land.

13. The *Tenure* on which the land is held; the compensation to be paid for the extinction or lease of proprietary rights; the amount of capital which will be contributed by the landowners, tillers, or local capitalists; the facilities, assistance, contributions, or guarantees which will be granted by the Government.

Government aid.

Reclamation of land.

The Reclamation of Land from the tidal action of the sea, or its recovery from rivers, lakes, or marshes in the interior of the country, is a branch of engineering reintroduced into England in modern times by the Dutch, who, in their turn, in still later times have been indebted to the aid of English engineers and contractors in carrying out such works in their own country on improved principles. Under this general title of Reclamation may be comprised works on any scale, from the filling or draining of a small lake or marsh on a private estate to the "warping-up" (the raising of land by the deposit of sediment from flood or other waters) and enclosure of large tracts of foreshore or estuarial flats.

Improved systems.

Reclamation works defined.

Reclamation Works may be broadly divided into two classes; the one, *Inland Works*, having for their object the reclamation of marshes, the shallower portions of lakes, the tortuous courses of sluggish rivers, or of land subject to flood-overflow; the other, *Tidal Works*, comprising all reclamations effected under tidal influence, whether in estuaries, deltas, or on the sea-coast. In both cases the return offered to capitalists generally consists of all or part of the land to be reclaimed, and concessions are granted or money borrowed on terms having such arrangement as a basis. In works of both descriptions

Inland works.

Tidal works.

drainage is an important feature. While works of this class are those that may appear the most easy to the uninitiated on account of the simplicity of the means and mode of construction usually adopted, yet, in fact, they require the exercise of considerable engineering skill. In those in which the control of river flood is the principal object, an examination of the entire *régime* of the river, from the upland districts down to its debouchement into the sea, and perhaps even the regulation of its whole course, may be necessary,—a matter which requires considerable hydrological study. Even if the enclosure of a certain amount of land in an estuary be the sole object, the navigation of the channel to which the river will be confined, as well as the general effects on the river and on the tidal action, become a matter requiring both consideration and experience; for any evils resulting from imprudent interference with the river's course are liable to perpetuate themselves and multiply to a serious extent. In the very simple case of the shortening the course of an overflowing river, with the object of reclaiming the land on its banks or the area occupied by its former winding channel, although no special skill may appear necessary, yet such works have often been effected in a manner involving damage to riparian interests lower down.

Drainage.

River regulation.

Among the tidal reclamations effected in Great Britain those at Romney Marsh, Morecambe Bay, the Fens in the Eastern Counties, on the rivers Dee, Humber, Forth, Tees, and Tay may be quoted as examples; and among those of the lake class, that of Lough Foyle, Lough Swilly, and some of the Swiss lakes. The experience these works afford points to the conclusion that simple reclamation works on a large scale are seldom remunerative to investors other than those locally interested, unless the land is so situated as to possess some special secondary advantages. Such advantages are those resulting from a combination with the reclamation of harbour or dock works, river improvement, sewage utilisation and irrigation, or railway communication; or from bringing into use existing embankments or canals; or from utilising refuse material, such as that of quarries or slag from blast furnaces; or from some other circumstances that either diminish the cost of the reclamation works or specially enhance the value of the land reclaimed To the value of the land actually reclaimed must be added in many instances the increased value given to the adjoining land in consequence.

Examples of tidal works.

Of lake works.

Indirect advantages.

The larger the works, the greater is the time required for the development of results; hence gigantic schemes of this nature can

Large schemes need Government aid.

See page 33.

only be entertained by investors under specially favourable conditions that include the aid of some Government subsidy or guarantee; such aid being sometimes granted on sanitary grounds for the benefit of the community. There are various ways in which the return to capitalists may be offered, but generally a share in the reclaimed land forms the basis of the arrangement. It is of importance that the promoters of such projects should not only demonstrate the practicability of the works, but should show that they will be remunerative within a reasonable time; that is, either that the land to be recovered will repay with considerable profit all the expenses to be incurred, or that the cost of the necessary works will be reduced by combination with other interests or existing works, or that some local or special considerations will give a higher value to the expected results than that merely of the enhanced worth of the land for agriculture.

Sources of profit.

Demonstration of profit by promoters.

On the other hand, when the reclamation works are of more moderate extent, such as will afford remunerative results within a reasonable time, the smaller amount of risk which they involve renders them far more acceptable to the investing capitalist, and, if the calculations be sound, places them in the category of profitable undertakings. Such projects have, however, been frequently laid aside for want of sufficient technical examination. For while many reclamation works have failed because of some rudimentary flaw, others which might have proved successful have been rejected for some invalid objection. For instance, the reclamation of a sandy foreshore has frequently been objected to by scientific persons on the ground that no crops whatever can be grown on pure sand. Undoubtedly the value of reclaimed land depends a good deal on the nature of the soil and its fitness for vegetation, and the alluvial bed of a lake has generally a higher value than a sandy shore; but on the other hand, sand, when it is to any extent calcareous, forms an excellent subsoil; it is more easily cleansed from saline matter than either clay or sandy loams, and it is more easily worked in the operations of drainage and tillage; while if it can, by warping or the application of sewage or useful sediment, be covered with even a small depth of alluvial matter, it may be easily transformed into useful arable land. In this way the sandy banks of many Indian rivers have been reclaimed, and by after-irrigation cultivated profitably. If non-calcareous, the sand may be advantageously mixed with clay, or clay with it, and the clay is usually not far off.

Fallacious objections.

Sandy foreshores objected to.

Adaptation of sandy soil.

General rules impossible.

It is obviously impossible to establish general rules in regard to these matters, and every project must be judged by the proportion which the trouble, expenditure, and risk will bear to the estimated results. In bringing forward projects of this class for the advice of a qualified engineer and for the consideration of capitalists, the opinion of an experienced land surveyor and a practical farmer may be taken with advantage. It is always advisable to include in the information furnished to them the accompanying objections, rather than to allow the objections to be raised afterwards, and perhaps magnified by persons not sufficiently acquainted with such matters, or who may be interested in opposing the scheme.

Difficulties should be avowed by promoters.

Protective works.

Protective works are frequently classed with those of land reclamation. They are, however, generally of much smaller scope and extent, having for their less pretentious object the prevention of further aggression on the land by the wasting action of streams and rivers, or of the damage caused by the sea; though sometimes they have the further object of recovering land that has very recently suffered injury from such action. It frequently happens that such works form an important part of a general scheme of reclamation; in which case it is advisable that their expected results be dealt with separately, as far as regards the economy of the undertaking.

Uncertain results.

The uncertain and apparently capricious results which follow the execution of protective works have been exemplified in cases where expensive dams having failed to divert the course of a river, a few judiciously-applied spurs or piles and loaded fagots have answered the purpose; or, on the other hand, in cases where groynes have been constructed with the object of resisting the action of sea waves on a coast, it has been found that nothing less than continuous lines of piling or connected embankments or sea walls could prove successful. These questions depend mainly on the action of currents, and it must be remembered that it is not the usual or average action that has to be dealt with, but exceptional occurrences from storms or floods. Great care is in many cases necessary to avoid reducing the tidal capacity of navigable rivers.

Interference with rivers, risks of.

Maintenance, danger of neglect.

The maintenance of reclamation or protective works requires perpetual care, any neglect leading frequently to a heavy expenditure. For example, the aggressive action of water on land recently reclaimed, may often at an early stage be combated at a few detached points by such simple means as the throwing in of broken stone, by a few stakes, the planting of saplings, or by turfing the banks; while at a later date a continuous protective bank set back from the water might become necessary to prevent further encroachment.

Preliminary information. In order to arrive at any trustworthy or useful decision with regard to reclamation projects, personal examination by an engineer is absolutely necessary. Much valuable preliminary information may, however, be collected and drawn up by local promoters of such undertakings, which may enable the engineer to judge of their merits in the first instance, and to decide whether the case is one worthy of a complete investigation. **Information classified.** Such information is indicated in the following list, and comprises the general and local conditions; the more precise particulars which may serve as the basis for the design and estimate of the engineering works; and, finally those of an economical nature, which may allow the value of the results, and the time in which they are likely to be realised, to be estimated.

Plan and levels. 1. A *Plan* of the area to be reclaimed, with a sufficient number of levels and soundings taken over it, referring to a given datum. The names of owners and occupiers should be marked on the plan.

Catchment area. 2. A *Map* of the surrounding district, including the whole of the catchment area of the river or lake (if the reclamation is of that class) under consideration, or, at least, the portion under tidal influence.

Sections. 3. Longitudinal and cross *Sections* of the area to be reclaimed, or a series of soundings at various points, showing the water-level at different stages of flood or tide, the latter being explained by tables showing the periodical spring and neap tides. **Samples of water.** Samples of water should also be taken at different depths under varying conditions of flood.

Sources of supply. 4. The *Sources of supply* of inland waters, if any; their extent, volume, and periodicity; the modes that can be adopted for diverting them and for utilising them.

Climate, rainfall. 5. The conditions of *Climate*, rainfall, and flood; their duration, extent, and effects; with any records of past physical alterations.

Alluvial deposits. 6. In works in which warping constitutes an important item, information as to the amount and quality of the *Alluvial matter* deposited by the waters, and its rate of deposit under varying conditions of stagnation and velocity.

Pumping. 7. In works in which pumping operations are likely to be considerable, data of the *Amount of water* to be removed, which will serve as a guide to the kind and amount of machinery required.

8. The extent to which *Navigation*, or other interests, such as foreshore rights, right of watering cattle, irrigation, fishing rights, water-mills or factories, may be affected by the proposed scheme. **Existing rights.**

9. Information concerning *Materials*, transport, and labour, such as has been already described. *See page 74.*

10. Exceptional occurrences or *Freaks of nature* to which the locality may be liable, such as excessively high tides and floods, alterations in the course of rivers, hurricanes, or earthquakes. **Risks of climate.**

11. The actual *Constituents of the soil* and subsoil, as ascertained by digging or boring, accompanied by samples and analyses of the land to be reclaimed, and of that in the neighbourhood, in its various stages of fitness for pasture, arable, or other purposes. **Condition of soil.**

12. Data of the *Expenditure* of time and money likely to be incurred in operations succeeding the simple reclamation and permanent enclosure of the land, such as the drainage, fresh-water irrigation in the case of salt marshes, manuring and improvement of the soil, trenching or other adaptation of the surface, or of any other operations necessary before the land becomes permanently fit for tillage or other intended purposes. **Estimate of after operations.**

13. The proprietary *Rights in the land* to be reclaimed, the tenure under which it will be held by those who are to till it; the value of land of various descriptions in the neighbourhood, and the selling price of crops; the distance from the markets; the means of communication in the district, and other data which may form a basis for estimating the value of the reclaimed land. **Tenure of land.** **Value of crops.**

14. The probable collateral *Profits* that may be obtained, and the extent to which assistance is directly or indirectly afforded by existing works or arrangements of any sort. **Collateral profits.**

15. The mode in which it is proposed to raise the *Capital*, and to apply the anticipated profits. **Capital.**

[*See also* CONCESSIONS: WATER-WORKS: TOWN DRAINAGE: PUMPING-ENGINES: PIPES: DREDGERS.]

CHAPTER IX.

WATER-WORKS.

Water-works first among Public Works.

THE supply of water stands first in order of importance amongst Municipal Public Works. It is impossible to lay down any rule as to the price which a town or district will pay for water, since it is by the need that exists, and by the difficulties of satisfying it, rather than by any fixed standard of value, that the price is determined. Where regular water-works are not established, their construction will always prove beneficial, and will generally afford a remunerative return for the capital invested. Some or all of the following advantages are generally obtained :—

Water-works generally remunerative.

Advantages afforded.

1. An increase in the Quantity of water.
2. An Improvement in the Quality.
3. Greater Regularity in the Supply.
4. Increased pressure available for Fire Extinction and Power.
5. A Reduction in the Price of water, or in the labour of obtaining it.

Secondary advantages.

It is hardly necessary to enumerate the other advantages, scarcely less important, which spring from these, such as the aid afforded to sanitary measures by the cleansing and watering of the streets, and the flushing of drains ; the erection of public fountains ; the watering of gardens ; the aid to manufactures ; and the extinction of fires. Time and trouble are saved to the inhabitants ; house property acquires an increased value ; and the district becomes generally a more desirable place of residence.

Water-works owned and managed by the Municipality.

In many British and foreign towns it has been considered to the advantage of the inhabitants that the water-works should be constructed by or for the municipality, and not for a private company, so that the entire control shall remain with those who are most interested, and any profit which may be gained shall be devoted to public purposes. Moreover, a municipality has certain advantages in regard to the acquisition of land, rights of way, laying of pipes in the streets, and enforcing of bye-laws, which it is not always expedient to confer on a private company. While in principle such an arrangement is desirable—and there are many cases where water-works are so conducted to the profit and advantage of the inhabitants—a municipality, whose members are not directly and personally interested in the pecuniary results, is not always so fitted for managing an enterprise economically as are private proprietors whose personal interests are at stake. Often in municipal bodies those who have the direction are too numerous, and have been elected for qualities other than those which would render them able managers. Changes in the management arising from party conflicts, or otherwise, hamper the carrying out of well-arranged plans; and in some cases even where there is no direct corruption, misapplied patronage will put the direction of affairs into incapable hands. But although in the majority of cases the establishment of water-works is still left to private enterprise, the proportion of such undertakings in the hands of the municipalities tends to increase.

Objections to Municipal management.

Cost of water-works, how defrayed.

See page 117.

The cost of establishing water-works may be borne in various ways. Where the works are undertaken by the municipality, funds can (in England) be borrowed on the security of the rates either from private investors or from the Public Works Loan Commissioners. If the works are to be undertaken by or for a private company, the enterprise is one peculiarly suited for support by local capitalists. None are so well able to judge of the need as those who share in it, and the undertaking is one of which the utility, even if not the means of performing it, is apparent. The parts of the enterprise which to local investors may be uncertain, i.e. the preparation of the scheme and the construction of the works, can be undertaken by others; for, by the employment of qualified engineers, the exact nature of the works which are necessary to produce certain desired results, may be ascertained; and able contractors will be found, to whom payment need only be made as the work progresses to the satisfaction of the engineer.

Suitable for local capitalists.

See page 22.

Preparation of scheme.

Specialist engineers.

See page 204.

Whoever may initiate the undertaking, it is necessary, as one of the first steps, that a feasible scheme shall be prepared and its cost ascertained; and for these purposes an engineer must be employed. The water supply of towns is a special branch of practice amongst engineers, and by the employment of such specialists the experience gained in previous similar works is rendered available. It may be that the source of supply is so obvious, and the necessary works are so simple, as to require no such special engineering skill; and in that case a local engineer, even without peculiar experience in such matters, can prepare the plans which will serve as a basis for an estimate of cost. But if the expense of bringing an experienced engineer from a distance be thus avoided, it is desirable in all but the simplest cases that the scheme be submitted to his inspection afterwards for approval or amendment. The information shortly to be described, or as much of it as applies to the case in question, should then accompany the plans, so that the engineer who is consulted may have the necessary material on which to base his opinion. This opinion having been obtained, those who are interested can judge for themselves whether to proceed further with the enterprise.

Alternative schemes.

Tenders from contractors.

Having ascertained that the cost of the necessary works is within their means, the promoters may then prudently seek to elaborate their scheme. The engineer may possibly have laid before them alternative plans, each having certain advantages of economy or fitness, and having reached this stage, the promoters, if they determine to proceed further, will generally find that the stronger position they have attained, and the means they have acquired of discussing the next step in the affair, amply repay the preliminary expenses they have incurred. Under the guidance of the engineer, and on the basis of the plans and specifications he furnishes, the promoters may then obtain from capable contractors absolute tenders for the construction of the works.

Joint-stock company.

If the capital is to be provided, and the undertaking carried through, by means of a joint stock company, a prospectus may be issued, and subscriptions invited on the preliminary report of the engineer before tenders are obtained; or if it be thought desirable to inspire more confidence in the sufficiency of the proposed capital than the report of the engineer affords, the company can be formed on the basis of an absolute tender from a competent contractor. This latter course is often adopted where the contractor is himself one of the promoters, or is willing to provide part of the capital, and it is then made a condition in the articles of association that the contract shall be made with him.

English usage often unsuitable abroad.

The works will probably not be carried out so cheaply in this way as in cases where all the capital is provided from municipal funds, or by a joint-stock company. But often in foreign countries the circumstances do not allow the formation of a company in the ordinary English sense; the promoters may be unable or unwilling to pay for the works with their own money, and the municipality may object to pay until the efficiency of the works is shown by their completion and operation. Although contractors as a rule avoid responsibility for the proper designing of works, and stipulate for payment when they have executed work as designed by others, there are capitalists, who for the purpose may be called contractors, who will incur the risk of such engagements, satisfying themselves, either through their own judgment, or by belief in the ability or reputation of the engineer who advises them, that the works designed will produce the desired results.

Capitalist contractors.

See page 41.

Concessions.

See page 18.

Reference has been made in previous chapters to the various methods by which Governments or municipalities may promote or encourage the carrying out of public works by private capitalists, and in many foreign countries the granting or selling of a concession is the usual method for water supply. While, however, concessions involving privileges, or which include guarantees or subsidies, may prove profitable to the promoters, capitalists, and contractors who share in them, it is questionable whether such methods are the best in the interests of the town, and whether the credit of the municipality, which makes their guarantee valuable, would not be better applied to the direct borrowing of money, which could be expended for the works in question without the burden of intermediate profits. But, while in English towns the borrowing of money for public purposes, on the security of the rates, is sanctioned by the law, and —as affording perfect safety to the capitalist—can be effected at very low rates of interest, such methods are not so well understood or so safely carried out in foreign countries, where, therefore, the less direct plan of granting concessions or guarantees is adopted. It frequently happens that water-works are wanted in towns where there are no local capitalists able or willing to provide money or credit—where, also, the municipality cannot raise the money—and the outside capitalists or contractors are asked to do everything. It may be assumed that the inhabitants have been awakened to the desirability

Guarantees inexpedient.

See page 33.

Concessions or guarantees, where necessary.

Concessions. *See Chapter II.*

of an improved water-supply; and the municipality, as representing the inhabitants, is willing to grant, to whoever will satisfy their wants, a concession which leaves a profit or return to be found in the sale of the water. The advantages which science and engineering skill afford generally allow ample profit for both sides; the new water-supply proves in every way better than that afforded by previously-existing means—and this at a price which, while cheaper or easier than before, allows sufficient margin of profit to the concessionnaires. Assuming that the municipality is in a position to inspire trust in the engagements it makes, it only remains to arrange the terms.

Monopoly of water supply. *See* MONOPOLIES, *page* 28. **Monopoly for term of years.** **Right of pre-emption.** *See page* 38. **Sinking fund.** *See page* 39. *See page* 35.

A monopoly should be conceded for a specific district, within which no one else is to be permitted to establish works or sell water. The length of time for which the monopoly is granted is an important point for consideration. Water-works require some years for their development, and the term is generally for a period between fifty and one hundred years. Fifty years is the shortest time which will allow the concessionnaires to reap a sufficient return for their outlay, and one hundred years is generally the maximum time for which a municipality will bind themselves and their successors, although concessions in perpetuity are not unknown. It is sometimes arranged that at the end of the term the water-works shall become the property of the town, either without payment or at an agreed price. Which of these conditions is equitable, and the length of time granted, depends upon the other conditions and on the amount of profit which is expected annually during the term. Of course, if the works are to be given up without payment, a sinking-fund must be provided out of the revenue to repay the capital. A concession, in granting privileges, imposes certain obligations in return, such as the construction of substantial works; the maintenance of a sufficient supply at a specified pressure; standards of purity; proper systems of distribution; and the supply of water at reduced rates for municipal purposes. Water should never be supplied gratis for public purposes; and if reduced rates are agreed to, the uses to which the water is to be applied should be exactly defined, for sometimes where the conditions are not clear, water nominally supplied for "municipal purposes" has been distributed to hospitals, schools, fountains, and other uses, to the loss of the concessionnaires.

Sale of water.

The sale of water may be effected in various ways. Where there are private wells, or other existing means of supply, the purchase of the water may be optional with the inhabitants, and in such a case the income to be derived from the new works is somewhat speculative.

Guarantee of revenue. *See page* 29.

Measure of price.

By meter. *See page* 203.

Water-rate based on rental.

Positive meters.

This uncertainty may be met to some extent by the municipality, and perhaps also private persons, agreeing in advance to take a certain quantity of water annually, at a fixed price; a small income may be thus secured, sufficient to induce the concessionnaires to risk the rest. The price at which the water is sold may be arranged in several ways. When large quantities are wanted for public or manufacturing purposes, the water may be measured by meter, and a price per 1000 gallons, per cubic mètre, or other unit agreed upon; but for ordinary domestic consumption there is the alternative plan of supplying the water for a fixed annual charge. Although the consumption does not exactly depend on the size of the house, the rental is a convenient basis for the calculation of price; and as, moreover, the rental is usually adopted as a basis for the assessment of taxes, the official valuations already existing for this purpose are available for reference, although they are not, without alteration, always suited for adoption. A rental rate is almost universally adopted in Great Britain where the collection of rates is simple and well understood, but in many foreign countries it is not so easy, and payment by measure is preferred. But a minimum charge should always be agreed upon, and a rate by meter beyond. Against this it is sometimes urged that the quantity consumed and paid for will be smaller unless a high unit of price is fixed. But although a less quantity may enter the consumer's house than under the rental-rate system, yet, owing generally to less waste, the quantity actually available for use is as great, and a payment of a sum equivalent to the rental rate is not objected to. The transaction is then as one for "goods sold and delivered" and the interference of any municipal authority or tax collector avoided. But much depends on the kind of meter employed. A "positive" meter such as is generally used in France is better than a merely inferential meter. The worst kind is where the quantity charged for is determined by the diameter of the orifice, for the consumer then has little inducement to avoid waste. This latter plan is only justifiable where the town is favoured with an almost unlimited supply.

Tariffs of prices for extra supplies.

Where the use of the water is obligatory on all houses—or practically so, by the absence of other good means of supply—the concession, if properly arranged, is of a character to induce the investment of capital. Besides the supplies for municipal and domestic purposes, there are generally other sources of revenue. Tariffs of prices may be arranged for extra private supplies: manufactories, baths, gardens, and fountains require water; if at a port,

High-pressure water utilised as power.

See TRANSM. OF POWER, *page* 488. WATER-ENGINES, *page* 609. HYD. CRANES, *page* 800.

See PIPES, *page* 650.

Monopoly of extra work.

the shipping also; and these afford sometimes considerable profit. A portion of the supply may be used as power for raising water to the higher levels of a town; the water thus utilised forming afterwards, if need be, the supply for the low levels. If the pressure in the mains can be always maintained at or above 40 lbs. per inch, the water is available as power for driving engines, cranes, and machinery, in factories, warehouses, and workshops; and, while thus affording a great convenience to the inhabitants—especially for industrial communities—the company opens out a valuable source of revenue. The transmission of power by water has in London, Birmingham, Liverpool, Hull, and other towns been carried to great perfection by "Hydraulic Power" Companies with mains charged with water at a pressure of 700 lbs. But though it is necessary, where such a high pressure is desired, to have separate mains for this purpose, the system may be applied at moderate though effective pressure in connection with the ordinary municipal supply. The concession may be made also to include a monopoly of all works in connection with the water-supply, such as the laying of new pipes, the connections and fittings in houses or wherever a connection or alteration has to be made in the pipes. A concession with such a monopoly, if a proper scale of prices be agreed upon, may be alike advantageous to the town and profitable to the concessionnaire.

Privileges needed by water companies.

Bye-laws.

Penalties for infringement.

Nature of bye-laws.

In arranging the terms of a concession, it is important to stipulate for certain secondary but necessary privileges, such as the right of way through the streets for extensions; free access, at all times, to the mains in the streets; the right of entry into houses, to inspect or alter pipes and fittings, for the prevention of waste or theft of water; and the right to erect new works. The conditions of this sort which may be necessary depend upon the special circumstances of each case, and must be arranged accordingly. Bye-laws are also necessary for protecting the property of a Water Company, and in Great Britain the Acts of Parliament authorising water-works undertakings so invariably allow such bye-laws, and provide penalties for their infringement, as to accustom the public to them as part of the ordinary law of the land. In countries where the British usage in such matters is not established, it is very important that the necessary stipulations be included in the terms of the concession, as it may not be easy afterwards to obtain them. Such bye-laws protect a Water Company against the theft, waste, fouling, or misuse of the water; give power to recover rates in arrear, and the right of cutting off the supply in case of non-payment. Although this last condition is almost invariably included in a concession, it is not always sufficiently defined in accordance with the law of the land to allow of enforcement; and generally to afford that legal protection which is equitable in return for the obligations undertaken by the concessionnaires.

Although a municipality may leave the concessionnaires to make their profit from the sale of the water, as just described, and may decline to guarantee permanently either a minimum revenue or interest on capital, an exception may be made for the first few years. The expenses of the first two or three years are not unfrequently large, and the anticipated incomings may be at the beginning so small as to forbid the hope of a nett revenue. The risk of this may be sufficient to deter capitalists from embarking in a scheme which they believe would in a few years' time be sufficiently profitable; and a municipality may find it to their advantage to encourage capitalists to construct their water-works by guaranteeing, for three years, or during the execution of the works, interest on the money invested. Where the capital is to be raised by means of a joint-stock company, such a limited guarantee is of very great assistance in inducing contributions.

First year's outlay unremunerative.

Temporary guarantees. *See page* 33.

Another shape in which assistance may be rendered in cases where the prospects of profit prove insufficient to attract capitalists or contractors, is by the municipality offering a subsidy in money to whoever will bring water to the town. In many cases such a subsidy is in the shape of a bonus or free gift, and the capitalists are still left at liberty to retain all the profit they can make from the works. But very often in return for the subsidy, the obligations of the concessionnaire are made more onerous; and both subsidies and guarantees have frequently the inconvenience of allowing too much official interference and control.

Subsidies.

See also page 27.

Official interference.

The *Systems* of water-supply are broadly classed as Gravitation and Pumping systems, and the cost of the works is of course primarily determined by the circumstances of each case, which render one or other system necessary, and by the extent and solidity of the works. A lake or source of supply situated on an elevation near a town, and affording always a constant supply of pure water, is a favourable instance of a gravitation scheme, and such a project is obviously much cheaper than one where the water has to be pumped and stored and filtered. It is, however, a mistake to suppose that gravitation schemes are necessarily the cheaper, and if an average could be arrived at, it is even probable that the cost, whether

Systems of water-supply.

Gravitation *versus* pumping.

Expenditure compared.

compared according to the quantity of water supplied, or per head of population, would be found to be greater than for pumping. In gravitation schemes the expenditure incurred for impounding-reservoirs for storing against dry seasons, and for the bringing of water long distances, is often so great as to exceed not only the cost of machinery necessary in pumping schemes, but even that of the annual expenditure for pumping, if the latter be capitalised so as to afford a fair comparison with the capital expenditure in a gravitation scheme where no pumping may be required.

High-level reservoirs.

High-pressure water for fire extinction.

See Fire-Engines, *page* 634.

Zones of different altitude.

Whatever be the original level of the source, it is in almost all cases considered best to bring the water into high-level reservoirs, from which it may flow downwards in its course to and through the town. The height of the reservoir determines several other points of importance. As water flows to its own level (subject to a slight loss by friction in the pipes and by leakage), a high reservoir will afford pressure sufficient to force the water wherever pipes are laid to an almost corresponding height in the town. Not only is this a convenience to the inhabitants, but it is of very great value in the case of fire, as the high pressure in the mains in the streets affords a supply, which (subject to certain qualifications) can be discharged at any point through a hose-pipe without the necessity for fire-engines. Where the supply of water is abundant it may, as already stated, even be used as a motive power for driving machinery. A pressure of more than 200 feet is inconvenient for domestic supply unless special fittings are used; but where this condition is attended to pressures even up to 400 feet may be used with advantage. Such a pressure discourages waste, because the slightest leakage is at once detected and demands attention and remedy; while with low pressure, leakage is sometimes allowed to continue for years. Smaller street mains and service pipes are also available. The cost of laying on water to a house is much reduced when a very small pipe will suffice, and an increased number of consumers is obtained—a point of importance where the use of the water is optional. (Service pipes even as small as ¼-inch internal diameter have in this way been occasionally used with advantage.) Where, however, the supply is at a greater elevation, the service reservoir is placed at a lower level; and if the town be situated on the slope, it may be divided into zones of different altitude, each zone having its own service reservoir.

Where the source of supply is not at a high level, or where there are no elevated positions available for reservoirs, tanks elevated on towers of brick or iron may be constructed. The iron tanks (supported on iron columns and girders) at Buenos Aires, capable of holding 60,000 tons of water, afford one of the largest examples. But where the cost of such elevated reservoirs or tanks is greater than can be afforded it may be sufficient to bring the water into the town at a very low pressure. In some cases pipes are not taken along all the streets, or into the houses, but merely conduct the water to local reservoirs, tanks, or fountains, from which the inhabitants can fetch their own supplies. This system, though seldom adopted in English towns, and though obviously incomplete, may be adopted where a cheap first cost is important, or where it accords with the habits of the people, leaving for future consideration or for after enterprise the greater conveniences of water inside the houses.

Elevated tanks. *See page* 863.

Low-pressure supply.

Supply confined to street tanks or fountains.

The *Quantity* of water required for a certain population depends on climate, on the habits and occupations of the people, on the mode of distribution, and on the waste. In England the actual quantity required for domestic purposes varies from ten gallons per head per day in small houses, to twenty gallons in large houses, and an average of fifteen gallons may be reckoned on as sufficient. But these quantities, while adequate even for towns where there is a constant service—that is to say, a supply always available in every house, by simply opening a tap placed in direct communication with the water-main, and not, as in many parts of London, a certain quantity discharged into a cistern once a day—do not include any but a moderate allowance for waste, and it is obvious that there is no limit to the latter under careless or incompetent management. For municipal and trade purposes, from seven to ten gallons per head per day is generally found sufficient, although this amount may be exceeded where there is a large demand for particular trades, for fountains, or other public uses. In those English towns where proper rules and regulations in regard to pipes and fittings for the prevention of waste are enforced, the total quantity consumed for all purposes is from fifteen to thirty gallons per head of population per day, while in others, where a wrong system or inefficient management prevails, the quantity ranges from thirty to sixty gallons. Efficient supervision to prevent waste costs less than additional interest on the increased capital expenditure which a large supply to cover waste will require; and if the latter system be adopted, a remunerative return to the investors can only be obtained by the imposition of high and burden-

Quantity of water how determined.

Consumption of water in English towns.

Allowance for waste.

Supply for trade and municipal use.

Fifteen to thirty gallons per head.

Waste prevented.

some water-rates. Where it is difficult or expensive to obtain pure water in sufficient quantity for the total consumption, two distinct services may be provided: one line of main pipes being charged at high pressure (from 100 to 200 lbs., according to the height of the houses) with pure water for potable and culinary purposes, and for fire extinction; and a separate service of unfiltered water for less important domestic use, for street watering, and other secondary purposes. If the latter service is also maintained at high pressure, it may be used for fire extinction, to the saving of the potable water. In view of the growing scarcity of pure water in the vicinity of large towns, it is probable that some such system of dividing the supply as is indicated above will have to be frequently adopted in the future.

Separate service for potable water.

Growth of population to be provided for.

In deciding upon the quantity of water to be supplied as the preliminary step for determining the kind and magnitude of the works, it is expedient to provide for a growth of population and an increased demand. In England, an allowance of from twenty-five to fifty per cent. beyond immediate wants is generally considered a prudent margin; but of course this question must in each particular case be largely decided by the probabilities of an increased population, on the extra cost involved in providing for it, and on the funds available. Moreover, in considering the question of cost, the trouble and expense which would be incurred in the future if works only for the present demand were constructed, must be compared with the cost of doing all at the beginning. Such a comparison will vary according to the nature of the works. Thus in a gravitation scheme, with impounding or storage reservoirs, and long lines of aqueduct, it will almost always prove more expensive to enlarge or duplicate such works in the future than to make them in the first instance sufficient for a growing population; while if the water be obtained by pumping, additional engines and even service reservoirs may be added in the future almost as cheaply as in the first instance, if land (and for engines, buildings also) be kept in reserve from the first. The margin of supply-power need not therefore in the latter case be as great as in the former. As, however, a stoppage in the supply of water to a town would be disastrous, apparatus—such as engines, boilers, and pumps—subject to accidents in working, or needing periodical repairs, should always be provided in duplicate from the first, though not necessarily in complete duplicate.

Future expenses for extensions compared with first outlay.

Duplicate apparatus.

Cost of water-works.

The *Cost* of water supply must obviously vary considerably according to the nature of the works, and in Great Britain the tendency has been towards an increase in cost, caused partly by the difficulty of obtaining new or additional sources of water in the vicinity of towns, and partly by the rise in the prices of labour and materials. Where the works have been well designed, and the consumption kept by efficient management down to twenty-five gallons per head per day, it will be found that the capital expenditure varies in all but exceptional cases from £1 to £3 per head of population. A larger cost can be afforded for the gravitation than for the pumping schemes, as the annual expenditure for pumping must be set against the interest on the excess of capital on the former. But in many towns the systems of water-supply have either been ill-considered from the first, or have been enlarged, supplemented, or altered without a fixed plan; or though well designed have had to overcome exceptional difficulties, and in such cases the expenditure reaches even £7 per head. In London and Liverpool the capital invested in the different water-works is about £4 per head of the population supplied. Where, as is often the case, the high cost has to be borne by the municipality, the inhabitants suffer by having to pay heavy rates, the investing capitalist having a fixed interest secured to him. But where private concessionnaires or water-companies obtain powers to supply a town with water, and agree beforehand to certain rates or tariffs of payment, they and not the inhabitants have to bear the loss if the expenditure prove more than was anticipated. There are, on the other hand, exceptional cases where a heavy expenditure at the first is a wise policy. For instance, in a large colonial city with a rapidly growing population, the most convenient source of supply, though far in excess of immediate wants, may require, to render it available or secure, an expenditure proportioned to the potential rather than the immediate benefits it affords.

Outlay in proportion to population.

Causes of heavy outlay.

High water-rates.

Heavy outlay sometimes justified.

The expense of Procuring and Distributing water will be found generally to range from 4*d.* to 9*d.* per 1000 gallons, these rates including interest on capital and current expenditure. The cost falls below 6*d.* only when an ample flow from unsullied rivers or artesian wells is obtainable. The rental rate for water charged in English towns ranges from 6*d.* to 18*d.* in the £ (in London it averages 12*d.*); but as the value of houses depends on many varying conditions which have no relation to the cost of water, these rates do not afford a fair comparison. A careful analysis in 1884 showed that the average charge for water in the undermentioned towns bore a proportion to

Working expenses.

Rental rate.

Average rate in English towns.

Sale of water by meter.

the rateable or net annual value of the houses as follows: London, 4·79 per cent.; Liverpool, 6·74; Manchester, 7·73; Birmingham, 7·71; Wolverhampton, 8·5. Where water is sold by meter a price as low as 4*d.* per 1000 gallons is sometimes charged, and in some cases as high as 2*s.*, but in almost all cases large consumers—railway companies, manufacturers, and others—are charged at a sliding-scale price, the rate being in inverse ratio to the quantity consumed. The cost and value of the water depend upon whether it has been purified for drinking, or is only fit for inferior purposes; upon the degrees of hardness, by which its fitness for washing and various manufacturing purposes is determined; and on the pressure, which may or may not take it to the top of a building or render it serviceable for driving machinery.

Tariff of prices.

Value of water, how determined.

Interest paid by water companies.

See MONOPOLY, *page* 28.

In Great Britain, the average dividend paid by water companies to their shareholders is about 7 per cent.; but it is to the monopoly they enjoy, rather than to any peculiar skill in administratration, that their prosperity is due.

Cost of foreign water-works.

In calculating the cost of water-works in countries where sources of water may be more easily accessible than in England, land more plentiful, and rights of way more easily obtained, there are frequently, on the other hand, expenses not incurred in England, of long carriage on pipes and machinery, import dues, and scarcity of suitable building materials.

Information necessary for a scheme.

Particulars classified.

The following is the information which is necessary as a basis for Designing water-works and for calculating their Cost. To the various particulars here described, an engineer on the spot would direct his attention, and the same information will aid engineers who have not seen the locality in suggesting the best methods and the probable expense, leaving the exact details perhaps for verification and final decision afterwards on the spot. As the information described is meant for general application and to cover a variety of cases, it is obvious that in every instance some of the particulars may be omitted and possibly others added.

Map.

Catchment area of rivers.

See also page 190.

1. A *Map* of the town and adjoining country, showing the positions of the wells, springs, rivers, or lakes, from which water may be obtained. Where there is a question as to the sufficiency of the water which certain streams can afford, a correct estimate can only be based on a knowledge of the extent of the catchment area of the rivers; the rainfall; the amount lost by evaporation; and the

absorption as determined by the geological formation. Neighbouring elevations, natural basins, and other sites suitable for reservoirs or filter-beds should be indicated; and the levels of the different sources should be given, as compared with some fixed datum in the town.

Geology of watershed.

2. As accurately as the circumstances will permit, the geology of the *Watersheds* or of the sites of wells; and wherever works are proposed, trial holes or borings should be made. A description of each of the sources of supply which are available for consideration, giving as nearly as possible the nature, quality, and amount of the water; the levels of water in the wells of the locality, the strata through which the wells penetrate, the quantity of water obtained from them, and how far, if at all, the supply is liable to be affected by mining operations or by contamination from surface drainage.

Water level. *See page* 630.

Flood levels.

3. If the sources from which the water is to be taken are periodically or occasionally flooded, trustworthy information as to the levels should be furnished, and the effect produced by the floods on the quality of the water described. If possible, the maximum quantity of *Flood water* per minute should be stated; also the dry seasons, if any, which produce scarcity of water should be described, and the maximum period of drought, in order that, if necessary, the scheme may include provision for the sufficient storage of water. A knowledge of the alterations in the levels of the sources is also necessary to determine the works at the in-take of the water; and in giving information on all these points, the experience of as many past years as possible should be furnished, so as to include exceptional as well as ordinary seasons.

Dry seasons.

Right of water.

4. The *Right* to take the water should be affirmed, and if in taking the water, existing rights of mill-owners or others below the point of abstraction are interfered with, the circumstances should be described, and the compensation or other terms which may be arranged. In connection with this, the number and value of mills interfered with should be stated; also whether the water is in such mills used for power or for manufacturing purposes; and if for power, the size of the wheels and the available fall. Any other public works, undertakings, or circumstances, in the neighbourhood of the town or of the water-sources, which may in the future be likely to affect the supplies, should be described.

Interference with vested interests.

Samples of water.

5. *Samples* of the water should be furnished for analysis, and the times and circumstances in which the samples were obtained care-

fully described. The samples should be transmitted in perfectly clear glass bottles, containing, if possible, not less than a gallon, well stoppered and sealed (not corked), and these samples should be accompanied by any analysis which may already have been made locally.

Existing water-supply.

6. A description of the *Existing water-supply*, showing the quality and abundance of the water at different seasons, and its cost to the inhabitants.

Water-power for pumping.

7. If it is proposed to take the supply from a river affording power for *Working pumps*, such particulars should be furnished concerning the fall available, the velocity of the current, and quantity of water per minute at different seasons, as will enable the engineer to consider the expediency of using water-wheels or turbines for raising the water, and for deciding upon the kind and size of such machines.

Street plan.

8. A *Plan* of the town on a sufficiently large scale, showing the principal thoroughfares through which the main pipes should be laid, the side streets in which pipes will be wanted, the position of public buildings or manufactories requiring large supplies of water, the sites for fountains, or wherever else water will be specially required. The levels of all these places should be given.

Materials and labour.
See page 74.

9. *Local information* of the kind described in a previous chapter, with regard to the landing and transport of materials, import duties, cost of building materials and labour, and especially with reference to the following points: The kind of gravel or sand obtainable as suited for filter-beds; of sand for mortar, cement, or concrete; clay for puddling; and clay, lime, hydraulic-lime, bricks, stone, slate, and timber, suitable as building materials; iron pipes, blue lead for pipe jointing; coal or other fuel for pumping engines, and the cost of such materials; a description of the kind of labourers and different kinds of skilled workmen, and the rates of wages.

Climate.
See also page 74.
Rainfall.
Frost.

10. The *Climate* should be described, not only as regards the points enumerated for railways, but with respect to the following: The rainfall for each month for as long a series of years back as possible, and how it has been ascertained; the evaporation, and how ascertained; the degrees and continuation of frost, and the depth to which it enters the ground; the thickness of ice on the rivers, and how often it occurs; the temperature, maximum and minimum, of the water to be used.

Site for pumping station.

11. If a site has been selected as suitable for a pumping station, the nature of the *Foundations* for building should be described, and

it should be stated if water other than that to be obtained for supplying the town is available for condensing the steam in the engine. No very pure quality is necessary for this, and surface condensers may be used, or the condensed steam and water stored and re-used.

Stratum in pipe trenches.

12. The kind of *Road material* along the lines of pipes and the subsoil in which trenches will have to be cut. As water pipes should not be placed in close contiguity to gas pipes, the position of the latter should be shown on the plan.

Tenure of land.

13. The conditions upon which *Land* can be obtained, the authority under which it may be taken, the tenure upon which it may be held, its value, and the cost of the process.

Population.

14. The *Population* of the town and district which is to be served with water, the rate of increase in the population during preceding years, and the probability for the future.

Number and kind of houses.

15. The number of *Houses* and tenements, and the rentals per annum, divided into classes, advancing by steps of about £10. The general height of the houses, and the maximum height.

Wealth and occupations of the people.

Nature of drainage. *See* CHAP. X.

16. Some information should be afforded as to the wealth and *Occupations* of the people, so far as will aid in estimating the amount of water required and the means of paying for it. Information under this head should tell whether the inhabitants wash linen at home; whether baths are usual in the houses; the manner in which the houses and streets are drained; and whether any complete system of drainage is established in the town, or is in contemplation.

Description of project.

17. If a *Scheme* of water-supply has been already prepared, a description of it should be furnished, showing the proposed methods of raising money, the terms of concession offered by the municipality and the calculations of cost, revenue, and profit.

[*See also* CONCESSIONS: IRRIGATION: TOWN DRAINAGE: TRANSMISSION OF POWER: PUMPING-ENGINES: PIPES: FIRE-ENGINES: WATER-ENGINES: HYDRAULIC CRANES.]

CHAPTER X.

TOWN DRAINAGE.

Necessity for drainage works.

ESSENTIAL as good drainage works are to the comfort and health of a community, they are seldom undertaken until the necessity is forced very strongly upon those concerned. Even in Great Britain, where civilisation might be thought sufficiently advanced to ensure a proper appreciation of such advantages, municipal authorities have always been backward in adopting improved methods of drainage; and this mainly because the expenses of new schemes are more apparent than the promised benefits. Old systems of drainage, or rude methods of removing sewage and refuse, are considered sufficient by those who are accustomed to them; and even persons of education cannot, or will not, in many cases, be brought to see how much the health of a town may be improved and its mortality diminished by proper drainage works. Although the scientific evidence on such matters is ample, and is confirmed by the statistics of the health of towns, the inhabitants and ratepayers, through the representatives whom they elect, will too frequently by passive or active resistance postpone as long as possible the necessary sanitary works; nor will the occurrence of epidemics always prove sufficient to rouse them. In England it is only since Parliament by legislative enactments has brought a superior power to bear upon all urban authorities, that those who were unwilling or unmindful have been forced to take the necessary action. If such has been the case so often in Great Britain, similar negligence in foreign cities, where public opinion is not so educated, is not astonishing.

Town authorities backward.

Opposition to sanitary works.

Town drainage enforced by Parliament.

Dangers of neglect intensified by climate.

In countries where the inhabitants are of inferior race, or of uncleanly habits, or where there are established defects in drainage, and especially in countries where the climate intensifies the dangers of neglect, the necessity for drainage works is even stronger than in England, and the results which such works afford proportionately greater. The advantages obtained are not to be measured only by the low average of mortality, but also by the diminution of sickness, and by the comfort and decency in daily life afforded to all classes of the community.

In Great Britain, the Urban Sanitary authorities of each town (generally the Corporation or County Council, or in unincorporate towns, the Local Boards of Health), are empowered by law to borrow money on the credit of the rates for capital expenditure on new works; and loans on the security thus afforded are sometimes granted from the public funds; it being a condition of such borrowing powers that a sinking-fund shall be provided, so that annually not only the interest, but also a part repayment of the capital shall be borne by the revenue of the current year. Some or all of the money is frequently advanced by Life Assurance Societies, who have to find employment for their large reserve funds, and who—unlike bankers—do not require a speedy return of the money lent, although they generally stipulate that the loan shall be repaid by annual instalments in a prescribed number of years. Although in the majority of cases such financial arrangements have proved successful, the question has been raised, and will probably receive considerable attention, whether the system is in English towns equitable. As the taxation falls exclusively on householders, and as many of the houses in English towns are held by annual tenancy or on short leases, the freeholder, on the expiration of the period of the loan, reaps all the advantage of the improvements, to which he may not have contributed anything.

Urban sanitary authorities.

Borrowing powers.
See also on page 117. LOAN COMMISSIONERS.

Sinking-fund.

Loans from Life Assurance Societies.

See BANKERS, *page* 43, *and* SYNDICATES, *page* 45.

Annual tenancy or English system unfair to householders.

The drainage works of London are, for purpose of construction and management, divided into two distinct classes, the main drainage and the local sewers. The main drainage was undertaken by the Metropolitan Board of Works (since superseded by the County Council), a constituent body formed for the purpose, although it performed many other functions. Most of the money for the large arterial sewers, reservoirs, and pumping stations which compose the main drainage system has been raised by loan as just described, and the security is considered so good that as much money as is required has been obtained at a rate of interest of from 2½ to 3 per cent. per annum. The taxation for paying the interest and repaying the principal of the loans (except those raised on the special security of the coal dues) is levied as a rental rate over the whole metropolitan area which is benefited; but the duty of collection is entrusted to the authorities of each separate parish or district, who are called upon

Drainage works of London.
See page 220.

Metropolitan Board of Works.

Rate of interest for loans.
See LOANS, *page* 31.

Coal dues.
See OCTROI, *page* 17.

Rates, how levied.

twice a year to contribute the quota which is due from them. It is endeavoured by periodical assessments of value to make the burden lie equally, so that a similar rental rate on all districts may represent a real similarity in taxation. The local sewers of the metropolis are constructed by the authorities of each parish, or group of parishes (called districts), from funds raised in a similar way; the duty of the local authority ending when the sewage reaches one of the main arterial sewers. The street-cleansing, removal of refuse, and general sanitary works are also managed and paid for by each district separately. The plurality of authorities who thus direct the municipal affairs of London is often a cause of great inconvenience; there is a want of uniformity in the management; the expenditure is unduly great; and reforms or improvements much needed are rendered difficult.

Local sewers of London.

Divided authority in London.

Provincial loans.

Most provincial towns in England are able to borrow money at rates varying from 2½ to 3½ per cent. per annum, there being various secondary reasons which in the minds of investors render such loans worth a slightly higher rate of interest than the metropolitan loans. The latter, being of larger amount, are more widely distributed and are better known; the growing value of the security is more apparent; trust funds may be legally invested in the stock; the interest is paid quarterly; and transfers can be effected in the metropolis. For these reasons the stock can at any time be easily disposed of—a point always regarded by investors as important, apart altogether from questions of security and rate of interest.

Metropolitan loans preferred by investors.

Colonial loans.
See pages 14 *&* 31.

The English system of providing funds is adopted in many of the colonies, but as local capital is not so easily obtainable at moderate rates of interest as in England, outside aid has often to be invited; and in the case of large towns, municipal loans are issued by the permission of the Colonial Parliaments, and are generally well regarded by English investors.

See Chap. III.

Contracts for foreign drainage works.

See page 40.

The terms upon which capitalists and contractors will carry out foreign projects have been already referred to. But conditions applicable to the special nature of drainage works are of course necessary, for there is the marked difference between drainage works and such undertakings as railways and water-works, that the former, in not being directly remunerative, lack the collateral security which the earnings of the latter afford. If, therefore, local funds are not forthcoming, outside capitalists will be more than usually cautious

Methods of raising money.
Concession granted. *See Chap. II.*
Payment by bonds. *See pages 27 & 30.*
Rio drainage. *See also page 30.*
Rental rates for house drainage.
Extra payments.
Subsidies.
Sewage the property of contractor.
See page 227.

in satisfying themselves that the security offered is sufficient. Sometimes, as in England, the municipality raises the funds directly by loan, pledges its credit unconditionally for payment of interest and capital, and then makes a separate bargain with the contractor for the works. In such cases, where secure money payments are to be depended on, contractors or promoters can expect a preference only where they afford assistance in other ways, such as by making the preliminary plans, or by subscribing to the loan. Sometimes, however, the municipality does not raise money directly by loan, but prefers to grant a concession to suitable persons willing to undertake the works. In such cases the contractor may be paid by interest-bearing bonds, which are to be redeemed at some period after the works are completed, the due payment being secured by the ordinary revenue of the town, or by the hypothecation of certain property or taxes. Another mode of payment (adopted at Rio de Janeiro) somewhat resembles that usual for water-works. Instead of taxing the general community, a special rate is levied upon each house according to its rental. The concessionnaires have the right, when they have conducted the drainage of each house into the sewers, to demand from the municipality annually a certain sum, and have the obligation and right of connecting the drains of new houses as they are built. As, according to this plan, a large outlay must be made before payments become due, contractors with considerable capital are alone able to undertake such works. An additional revenue is sometimes obtained from the town as payment for the ordinary street drainage, and sometimes a subsidy in money is given besides. It only depends upon the terms of such engagements to make them as profitable as those for any other public works. The bargain generally grants to the concessionnaire the property of the sewage as manure; but it has been sufficiently shown that the value of the sewage will not alone compensate for the works and labour of removal; and unless there be unusual facilities for its immediate conveyance to agricultural land, the sewage has to be filtered, deodorised, or otherwise rendered inoffensive by the contractor before it can be made available as manure, or the effluent water be allowed to flow away. All these conditions are obviously matters for special arrangements in each case.

Methods of drainage.

In deciding upon the methods of drainage which are best suited to any particular locality, considerations of economy affect the question in various ways. The truth of the proposition that sewage

Sewage should be utilised on land.

should be given to the land is universally acknowledged, and sanitary engineers in all countries would willingly conform to such a law of nature, and not only thus find a means by which they can be rid of the sewage, but at the same time make its disposal a profit instead of an expense. Differences of opinion amongst engineers on this point have been magnified because of the very different sides from which they approach the question, and from the want of experience or trustworthy data. Some, in their earnest desire to utilise the sewage, and in the very sanguine hopes they entertain of success, are apt to risk failure in the primary and more important sanitary task. The size of large cities, the crowded population, the manner of conveying the sewage, the absence of a regular water supply, the method of purification, the want of suitable land, the difficulties of applying the sewage, and the very low value it possesses (especially when diluted by street drainage) in proportion to its bulk, are obstacles which, singly or together, have up to the present time, in the majority of cases, baffled the ingenuity of those engineers who have sought to make sewage irrigation profitable. There are cases where crude sewage can, with advantage, be put upon the land, and the time may come, as other kinds of manure become more expensive, when sewage will have such an increased value as to justify more frequently the cost of so using it. But so long as other manure can be more easily or cheaply obtained, it would be as wasteful to apply the sewage (unless for sanitary reasons) as to take pains to utilise some waste material for fuel when the equivalent in coal could be purchased at a less price. There is, perhaps, no problem among those which the engineers of the future have to solve which is more important to the welfare of mankind than the economical disposal of sewage and town refuse, and in no branch of engineering are there such marked differences of opinion; but if it be acknowledged that the sanitary work is a necessary and legitimate cause of expense, experience has already sufficiently accumulated to show the means—single or together—by which the desired result can be achieved.

Differences of opinion.

Difficulties in utilising sewage. *See page 224.*

Measures of value for sewage.

Wasteful application of sewage.

Proper systems available.

Climate and circumstances vary.

The climate and the local circumstances in most foreign towns differ so widely from those in England, that the systems of drainage and the methods of procedure usual in English towns cannot always be applied. In countries subject to alternate dry and rainy seasons the arrangements for street cleansing must necessarily be different from those in England, where periods of more than a few days without rain are rare. An insufficient or irregular water-supply is also a great cause of difficulty, and where no regular water-works exist, their construction either in conjunction with or as preliminary to the drainage works is an essential part of any complete sanitary scheme. The house fittings and sanitary appliances are in most towns not of English origin of an insufficient and backward kind, and the inhabitants have generally standards of comfort and decency which would be unendurable amongst an English-speaking people. Modern travel, and the comparisons—so disadvantageous to themselves—which such intercourse forces upon foreigners, is leading to the introduction of English systems abroad; but the expense which such systems involve, generally forbids their adoption when only increased comfort or decency is the anticipated benefit; and it is the occurrence of epidemics, or a permanently high death-rate, which finally induces the adoption of improved methods.

Insufficient water a difficulty. *See* WATER, *Chap. IX.*

Foreign sanitary works backward.

The liquid sewage of a town consists of the surface and subsoil water resulting from the rainfall, which brings with it the street sweepings and other surface impurities; and the sewage from houses, stables, and factories. Where no proper system prevails, the street drainage is generally allowed to flow along open gutters (into which often the house slops are emptied), and thence by ditches outside the town into the nearest river. These open conduits are not only offensive to the sight and smell, but too often also spoil the wells of the locality. The evils of such a system are reduced to a minimum when the gutters are well flushed; and in towns possessing an abundant supply of water, a copious and continuous flow along the street gutters tends to render them innocuous. In the case of towns situated on low-lying or marshy grounds, surface and subsoil drainage is a matter of great importance, quite apart from the more difficult question of house sewage. Although in the great majority of cases where improved systems of drainage are established, the two kinds of sewage are treated together—the rain-water and street gutters helping to flush the drains which convey the house sewage—it is the opinion of some engineers that the two should be kept distinct, so that the house sewage, no longer diluted, shall retain its full value as manure; and in countries subject to heavy rains it is impossible to provide for rain-water in the sewers. The separate system finds its chief justification in those cases where the sewage has to be lifted by pumping (and where, therefore, it is desirable to reduce the bulk and weight), and where the sewage is allowed to flow on to land in a crude condition.

Town sewage.

Improper systems.

Flushing of open conduits.

Sewage kept separate from rain-water. *See page 224.*

Disposal of house-sewage. At present, house-sewage is disposed of in various ways. The old-fashioned middens and cesspools are still used in a vast number of cases, and in crowded towns cannot be too strongly condemned. **Evils of cesspools.** In some cases the cesspools are periodically or occasionally emptied, and their contents buried in waste land, or taken to agricultural land for manure, or thrown into the sea; in others, they are never emptied, and when full others are used in their stead. In towns where the means or disposition to construct sewers are wanting, or where the absence of a regular water-supply would render removal in a liquid form difficult, or where the inhabitants, from their ignorance or prejudices, would be likely to neglect or misuse the arrangements necessary to water-carried sewage, then these ruder systems must be made the best of. In most towns a regular organisation exists for the removal of ashes and other house refuse, and by an extension of **Dry-earth and pail systems.** the same organisation to the "dry-earth" and "pail" systems, it is attempted to remove sewage matter from houses in a solid or semi-solid form; but, to render such methods successful and inoffensive, every part of the apparatus must be properly designed, each detail **Precautions necessary.** in the operation suitably arranged, elaborate precautions taken for cleaning and deodorising, and the supervision must be constant and **Difficulties.** vigilant. The difficulties which generally hinder the adoption of these systems are none the less because they are made up of details, for the minor inconveniences of periodically entering private premises, of carrying and carting offensive matters through the streets, and of disposing of them promptly, are—if the English standard of decency and comfort be considered—very great; yet in towns without water supply and closets after the English fashion, such a carefully-organised system of periodical removal may be the best. Such systems, however, find their easiest application in villages or small towns. So **Conditions of success.** much depends on the local circumstances of each case, the size of the place, the situations of the houses and offices, the supply of suitable earth or other deodorants, facilities for removal, contiguity of agricultural or waste land, and other essential conditions, that the plan cannot be recommended for general adoption in large towns. Those who defend the pail and cart method not merely as a substitute under certain circumstances for the water-carried system, but as superior even where there are available sewers and abundant water, are apt **Ventilation.** to overstate the disadvantages of the latter; but the anticipated evils need not arise if proper attention is paid to ventilation, and if there are the same care and supervision as have been bestowed in those towns where the pail system is cited as successful. It is the misuse of the water-systems which alone renders them open to condemnation. It must, moreover, be borne in mind that all other methods of dealing separately with house sewage can only be adopted as supplementary, and not as a substitute for the water-carrying of sewage, the liquid sewage of a town almost always containing the largest share of impurities.

Water-carrying of sewage.

The facilities which a regular water-supply affords for the removal in sewers has caused such methods to be adopted with too little regard to the ultimate disposal of the sewage; and where, in countries like Great Britain, with an increasing population, it is allowed to flow in a crude state into neighbouring streams or rivers, the pollution of the rivers (especially those of small volume) has become intolerable. Even where the discharge is so arranged as not to inconvenience the inhabitants of the town, the nuisance is only removed to those who live further down the river, who in many cases not only suffer discomfort, but find their supply of drinking water fouled beyond endurance. So glaring did the evil become in England, that the Rivers Pollution Prevention Act was (1876) passed to forbid the discharging of crude sewers into rivers; and the sea, in cases where the sewage is a nuisance, is included in the prohibition. Although in England, consideration for the vested interests of manufacturers has prevented the same interference with the fouling caused by trade refuse, legislation has been directed towards a reduction of this evil also; and if, to avoid infringement of the law, manufacturers discharge their trade refuse into the public sewers (thus casting upon the community the burden of disposing of it), the same Act of Parliament provides for their contributing to the expense. As such legislation occurred at a time when the drainage of towns had been enforced by other sanitary enactments, urban authorities found themselves in peculiar difficulties. And as the drainage of a district must eventually reach the rivers, purification through the natural filter of land, or by artificial means, became necessary.

Removal in sewers depends on the water-supply.

Pollution of rivers.

Rivers Pollution Prevention Act.

Fouling caused by trade refuse.

Stringent enactments in England.

The arrangement of houses and streets in the European manner, with an established water-supply, being accepted, it may be assumed that removal in a liquid state is in the majority of cases the most preferable method available, and the following are briefly the means necessary to the proper cleansing and drainage of a town :—

Means for cleansing and drainage.

1. The streets must be properly sloped, and channels provided

Street cleansing.

for conveying the rain-water through gratings into underground drains, the openings being properly provided with stench-traps or deodorisers.

House refuse.

2. Proper regulations must be made for the periodical removal of ashes and other house refuse; and for the removal from streets, markets, and slaughter-houses, of snow, filth, garbage, and rubbish.

House drains.

3. Every house must be provided with suitable domestic fittings, and means for the conveyance of sewage into proper drains.

Arterial sewers.

4. Sewers of proper shape and size, to which the house drains must communicate, must be constructed in every street, converging into larger arterial sewers, and there must be a sufficient water supply to ensure a proper flow and periodical flushing.

Disposal of sewage.

5. The liquid sewage must be conducted either—

See page 219.

(*a*) Into the sea beyond low-water mark.

See page 220.

(*b*) Into tidal or other rivers of sufficient volume to carry away the sewage without excessive pollution.

See page 221.

(*c*) Directly on to land and disposed of by irrigation.

See page 222.

(*d*) Or into precipitating tanks for treatment by chemicals: the effluent, more or less purified, passing directly, or after filtration through land, into a river or the sea; and the residuum—more or less effective as manure—on to land.

The above means may be further explained as follows:—

Bye-laws for streets.

1. In most civilised towns there are established regulations or bye-laws for the width and formation of streets, and for their drainage; and where new lines of houses or streets are constructed by private persons, conformity to the bye-laws is a condition precedent to the streets being opened for traffic and taken over for future maintenance by the municipality.

Removal of house refuse.

2. The removal of sweepings from streets; of ashes, bones, broken earthenware, and other domestic rubbish from houses; and of offal and garbage from markets and *abattoirs*, is almost as essential to health as is the riddance of sewage. The removal of refuse is generally managed by municipal officers, who employ for the purpose either workmen at day wages, criminals, or paupers; or by contractors, who, providing labour, carts and appliances, are paid either by money or by the refuse which they remove.

By whom managed.

Accumulated refuse a source of disease.

Although in most towns there are such arrangements for dealing with refuse, its presence in the streets or near houses before removal, and its accumulation in the vicinity of the town afterwards, are fruitful sources of disease; and too often the evils are perpetuated by the building of new houses on or close to land formed of decaying rubbish heaps. Even when deposited at a distance from the town the refuse, unless effectually buried, is still a source of danger. In large cities like London or Paris there are few persons, even among those officially connected with sanitary affairs, who are fully aware of what does become of the refuse. Although in some parts of London the collection and disposal of the refuse are entirely in the hands of contractors, who have by experience discovered the various ways in which the refuse can be utilised, in most of the districts the work is done entirely by the municipal authorities. In the central district of London the refuse is sorted. After picking out the old metals and bones, which have a ready sale, the harder substances, like broken crockery, are utilised for road-making; cinders or ashes are sold to brick-makers; and market garbage and street-sweepings are sold or given to farmers as manure, and the worst kinds of offal are burnt. This sorting of the refuse has, by a liberal expenditure on buildings and sanitary appliances, been rendered as harmless and inoffensive as possible to the workpeople, many of whom are women. Machines have even been devised for separating the various classes of refuse, but though worked with some success, they have proved a nuisance in the vicinity of dwellings. The "slop" or road-mud, which contains so large a proportion of road detritus, is in some cases washed for the sake of the sand in it, which can be used for mortar; but in most cases it is utilised for the raising of land or embankments, or in road-making as a substratum to the harder materials. The last resource of carrying the refuse in barges and discharging it into the sea, is occasionally resorted to.

Subdivision of refuse.

Refuse, how disposed of.

Separation by machinery.

In several English and foreign cities where other means have proved insufficient or unhealthy, it has been attempted, with increasing success, to deal with house refuse, offal, and garbage of all kinds by Fire, and as burning in an ordinary furnace would be difficult or offensive, special furnaces (known as destructors) have been devised for the purpose. These furnaces, which are built of iron and brickwork, are so arranged in regard to draught and chimney as to emit no noxious gases, while at the same time they reduce to innocuous cinder or clinker all that is put into them. As there is no storage, the furnaces work day and night, and, dealing with the refuse as it arrives, there is no nuisance at the site. The English custom of open fires in houses provides in the domestic refuse enough half-consumed cinders to serve as fuel, but even in

Refuse treated by fire.

Destructors described.

Combustibility of house refuse.

Quantity according to population.

Capacity of apparatus.

Cost of process.

Cost of apparatus.

Sale of products.

Heat from destructors utilised.

See page 571. Steam from Coal.

cities where closed stoves are used, which leave no combustible ashes, there is generally enough carboniferous matter to keep burning, when the fire is stimulated by a steam jet, or other artificial draught, with little or no fuel addition. In English towns the refuse, exclusive of street sweepings, approximates to one-quarter ton per inhabitant per annum, so that in a town of 100,000 people, about 25,000 tons have to be dealt with yearly. The destructors are composed of a series of cells or chambers, each of which will, with the refuse, offal, and garbage usual in England, and with good workmen earning 30*s.* a week, burn about eight tons of refuse per day. But in foreign cities with less efficient labour available, the quantity sometimes is as low as five tons per cell per day. The cost of burning, including interest on capital, depreciation, and all charges other than the expense of carting the refuse and the cost or rent of land, ranges from 18*d.* to 24*d.* per ton of refuse destroyed, but 3*d.* to 4*d.* may be recouped by the sale of the products. The cost of a destructor of not less than twelve cells ranges from £500 to £800 per cell, including all building and brickwork, but exclusive of land. The lower rate is only possible by using cheap sheds of corrugated iron instead of the more substantial and permanent brickwork. For a 12-cell plant 4000 square yards of land, or 3000 metres, equal to about three-quarters of an acre, will suffice, including storage room for clinkers. The latter are in some cases used for grinding into mortar, or as material for road-making, or as railway ballast. In some cities the heat from the furnaces is used for boilers giving steam power to engines for grinding mortar, or for electric lighting, or for tramways. But one pound of refuse will raise only about one pound of steam as compared with ten pounds from coal. Therefore, while such a use of it, of course, reduces the expense of the destructor, it is a mistake to suppose, as is sometimes stated to be the case, that the burning of refuse will not only defray the cost, but be a positive source of profit. The removal of a nuisance must be deemed the primary object in view, an advantage which must be paid for.

Bye-laws for house fittings and drains.

3. The sanitary fittings of houses, and the proper connection of the house-drains to the public sewers, are of primary importance, and bye-laws which embody the necessary regulations are an essential part of all municipal drainage schemes. Such bye-laws define different kinds of buildings, prescribe the strength of walls, the ventilation of rooms and offices, and the shape, size, and position

of drains, with their connection to the public sewers; and although the owners or builders of houses have to bear the cost of all the arrangements, it is a usual regulation that the necessary sewer connections (in order that they may be effectual) shall be made by the servants of the municipality.

Improvements in sewers.

Ventilation.

Concrete.

See pages 122 *&* 140; *and* CEMENT, *page* 849.

4. In regard to the kind and arrangement of sewers, much valuable experience has accumulated during the recent years of municipal improvements, and well-established rules for the shape and size of sewers, and the fall which is necessary for a certain flow, are available for future guidance. The importance of ventilating all sewers, both public and private, and of properly trapping all sewer-connections, has become more thoroughly appreciated. Portland cement concrete has in some cases (both in Europe and America) been substituted with advantage for brickwork in sewer construction and for stoneware in drain-pipes. Engineers are also assisted by the numerous inventions of stench-traps, deodorisers, and other sanitary appliances, conducive to cleanliness and health.

5. In regard to the different methods enumerated on page 216 for the disposal of liquid sewage, it may be said that:—

Discharge of sewage into the sea.

See page 223.

Inefficient methods.

Remedies.

(*a*) *The Sea as a receptacle for sewage* is generally preferred when it is contiguous to the town, for though sewage valuable as manure should not be thrown away or wasted until full consideration has been given to plans for using it on land, the trouble and expenditure necessary to such utilisation generally appear to outweigh the promised results. In many English coast-towns the method of discharging the sewage into the sea is inefficient and dangerous to health; but by legislative enactments, the local authorities will be compelled to amend defective systems. In the coast towns of other countries, the standard of efficiency is generally much below that of England. For instance, the sewage is often offensive when it is discharged into the sea in the immediate vicinity of dwellings,or at a point above low-water mark, or where—as often happens in an inland sea, or in a land-locked bay or gulf—there is little flow of tide, or where the currents are principally in-shore. Such evils may generally be rectified by extending the discharge-pipes further into the sea, or by conducting the sewage to an outfall on the coast more remote from the town, or to a point where the currents are more favourable; and such precautions sometimes involve the construction of pumping-engines for raising the level of the sewage. During the time that the outlet is closed by the tide, the sewer (although the sewage may be expelled) becomes in effect a large cesspool, and special precautions—sometimes involving great expense—are necessary to ventilate the sewer and prevent the foul gases from rising through the drains into the streets and houses. When, owing to special circumstances, the discharge of crude sewage into the sea cannot by any of the above means be rendered inoffensive, then a certain preliminary treatment of the sewage, such as is presently described in connection with its discharge into rivers, becomes necessary.

Ventilation of tidal sewers.

Discharge of sewers into rivers.

(*b*) *The discharge of sewage into Rivers* has been the method almost invariably adopted in towns not situated on the sea. In England there are none but tidal rivers into which crude sewage can be properly discharged, for although a running stream has wonderful powers of recuperation, offensive mud banks are deposited; and as the population is generally dense, and the rivers small, the sewage is inevitably a nuisance to towns and villages below. In new or sparsely-peopled countries the crude sewage of a town may be discharged into inland rivers; but evil results cannot be avoided, and as population increases, the fouling of the stream will, as it has done in England, prove a nuisance.

Evil results.

Strong current required.

See HARBOURS, *page* 121.

Shoals formed.

Even where there is a tidal river of large volume, sewage can only be inoffensively discharged, if the current be strong enough to bear it quickly away into the deep sea without depositing it on the banks or shoals. The circumstances which cause a bar to form a natural deposition at the mouth of a river apply to the suspended matter in the sewage also, but in sewage there are heavier and more adhesive particles than the natural alluvium, and the liability to form shoals is proportionately increased. Where the drains discharge directly into a river as it flows past a town, and especially when such discharge is continuous, the stream must obviously be fouled, and dredging to remove the banks probably rendered necessary; the degree of nuisance being measured by the volume and velocity of the stream as compared with the amount of the sewage poured into it.

Discharge of London sewage into the Thames.

See also page 210.

The manner in which the sewage of London is discharged into the Thames will illustrate the methods which have been considered efficient. Up till the year 1860, local sewers emptied into the Thames at all parts of its course through the metropolis, and the fouling of the stream became at last unbearable. Since that date long lines of main sewer have been constructed on each side of the river, which intercept all the previously existing sewers, and convey their contents to points about twelve miles below London Bridge, where the river runs for a considerable distance between uninhabited marsh lands; pumping-stations at various points on the route raising the sewage to the level necessary for a proper flow. At the stations, proper means are taken by a system of scavenging and of catch-pits to remove large substances and the heavier silt or road-grit, and up till about 1886 the crude sewage with only this preliminary treatment passed into the river. In deciding upon the capacity of the main sewers, a ¼ in. rainfall in each 24 hours was assumed. Exclusive of heavy rains, the ordinary flow of sewage amounts to 120 milllons of gallons per day. In dry weather the discharge is made only for about two hours after high-water, but the ramifications of the sewers are so complete, and the rain-water finds its way to the outfall so quickly, that the main sewers have proved to be not large enough to store the water between the tides, and when there is more than a slight rainfall the discharge into the Thames becomes of necessity more or less continuous. Moreover, with heavy rains the pumping power is insufficient, and the safety-outlets which have been provided from the local sewers into the old river outfalls are called into use, though of course the discharge from them is at such times much diluted. The river, in its course through the metropolis, was greatly purified, and where foul odours and offensive mud-banks formerly prevailed, the only impurities are those from shipping and small local drainage along the riverside which cannot be avoided; and the banks at low water exhibit an almost clean shingly beach. But it was found that the sewage matter floated up and down with the tide, taking many days to reach the sea, and that during that time much of it is deposited on the bed and sides of the river. If this deposit occurred only below the outfalls, constant or periodical dredging would probably be the cheapest remedy until an increasing riverside population rendered such means ineffectual; but it was found that the sewage matter is carried by successive tides up the stream; and it proved also a nuisance to the inhabitants on the river banks between London and the outfalls. While, therefore, the construction of the main sewers may be considered as a great work admirably executed, the method of disposing of the sewage was not entirely successful; and about 1886 steps were taken to amend it. The proper remedy would probably have been found in the extension to the sea of the main sewers, which would discharge their contents, either directly into the sea or on to the large area of waste and sandy shore which the estuary of

Pumping-stations.

Catch-pits for road-grit.

Provision for rain-water.

Sewage discharge continuous.

Advantages obtained.

Mud deposits.

Dredging.

See DREDGERS, *page* 832.

See page 209.

Further works necessary.

the Thames presents. But as a cheaper alternative, the sewage has received a preliminary chemical treatment at the present outfalls, with the idea that only a sufficiently-purified effluent should reach the stream. Somewhat the same method was successfully adopted as at Rio de Janeiro. The settled sludge in the London case ranges from 2000 to 3000 tons daily, and it having been found impossible to dispose of this for manure, even by giving it gratuitously, the plan was tried in 1888, and has since been continued, of conveying the sludge to sea in steamers of about 1500 tons burden, and discharging it in deep water. As the number of houses and population increase, this method also is likely to prove insufficient, and the sewage itself will have to be taken to the sea. The road *detritus* is one of the difficulties in the dealing with London sewage, for as most of the streets are paved or macadamised with granite, the quantity washed into the sewers is very great, and notwithstanding the precautions (already involving trouble and expense) at the outfalls, much of it passes into the river and sinks to the bottom; and although the scour of the current keeps the main channel clear, banks are formed which have to be removed by dredging. The amount of London sewage to be dealt with is so great, that discrimination is needed in rejecting the outfall system as inapplicable to other places. But where no river of sufficient volume (in proportion to the sewage) is available, method *c* or *d* must be resorted to.

See page 211.

Deposit of road grit.

Involves dredging

London not a fair precedent.

See page 217.

Sewage land-irrigation.

(*c*) *Sewage irrigation* has been attempted in many ways, and if looked at only as a means of riddance, the experience gained since 1850 with the sewage of English towns proves that in the majority of cases such a method either by itself or when allied with other means may be adopted. When, however, the pecuniary results are investigated, it is found that only in rare cases, where there is a combination of favourable circumstances, does the use of the sewage as manure repay the cost; and even where the farmer may use the sewage profitably, the question is, for the town or municipality, narrowed to a calculation of the annual expenditure which must be incurred; the least favourable cases showing that some other and less expensive manner of disposal must be adopted. The circumstances that are favourable to a profitable use of sewage as manure are the following: the contiguity of agricultural land or waste land that can be fertilised, and facilities for conveying the sewage; such a level and position of the land in regard to the town and to the line of sewer, that the sewage can be brought, without pumping, to the site, and that

Profit cannot be obtained.

Favourable circumstances enumerated.

Levels.

it will, without being artificially raised, flow on to the land, which must be so situated that it can be under-drained or possess a natural under-drainage of from 4 to 6 feet deep. The price or rental of the land, and the expense of preparing or laying it out to receive the sewage, must be moderate. There is often a great prejudice against selling or letting land for sewage irrigation, and prices or rents are demanded far in excess of its agricultural value; and if, for any reason, it is impossible to acquire at a reasonable price a sufficient area in the vicinity of the town, it becomes necessary to carry the sewage long distances. Unless there be a falling gradient along the line of sewer, one or more pumping-stations are required, and an annual expenditure, as well as an increased capital outlay, is incurred. Liabilities of this kind are among the various causes for the great and unremunerative outlay sometimes incurred by municipal and sanitary authorities on sewage farms. The expenses of laying out or adapting lands are also sometimes a great burden on irrigation schemes. As much as £200 per acre has been expended in cases where £10 per acre is all that could properly have been afforded. On the other hand, there may be cases where, owing to the limited quantity of land available (and other methods of sewage disposal being more costly), an elaborate preparation of the land as a filter-bed may be the best means left to adopt.

Price or rental of land.

Pumping-stations.

Expenses of adapting the land. *See also page* 181.

Filter-bed.

The quantity of land required for the sewage of a certain population varies according to the quantity and kind of sewage, and the character of the soil. The quantity of sewage depends upon the water-supply and the rainfall, and is in English towns generally some amount between 20 and 70 gallons per head per day, 30 gallons being a fair average; the larger the quantity the greater of course the dilution. If the land be calculated according to the necessities of agriculture—as for corn or ordinary grass—one acre would not require as an average daily supply more than 2,000 gallons of sewage; for in English towns where modern systems of sewage-irrigation have been tried with a view to obtaining a farmer's profit, an average of one acre of land for sixty of the population has been found requisite; but where purification of the sewage is the sole object in view, and where the sewage is subjected to preliminary treatment, the same area will, under favourable conditions and proper management, serve for a much larger population.

Quantity of land required.

See WATER-WORKS, *page* 201.

Gallons of sewage per acre.

Vegetable produce has generally a high value in the vicinity of

Crops suited for sewage.

large towns, and sewage has been successfully applied to mangold-wurzel, osiers, and Italian rye-grass; but in the majority of cases the latter has been found to be the crop most easily obtained, and the one least liable to injury by sewage in large quantities.

Money-value of sewage as manure.

Nitrogen lost.

Barren land benefited. *See* RECLAMATION, *page* 187.

The value of crude sewage as manure depends mainly on its degree of dilution, and in England the average value set upon it (if the best Peruvian guano and the superior kinds of phosphates be taken as standards of value) has varied from 1*d.* to 3*d.* per ton delivered on to the land to be irrigated. Later experiments diminish even this estimate of value, for it has been found that of the nitrogen which (as in guano) is the principal fertilising ingredient contained in the sewage, at least 50 per cent. passes away in the effluent water unabsorbed by land or crops after the sewage has filtered through the soil. If in England such are the pecuniary conditions, they must be less favourable in those foreign countries where agricultural land is less dependent on manure, and where crops have a lower value; while, on the other hand, of course, there may be cases where there is barren land near a town which, by sewage-irrigation, may be rendered fertile.

Sewage separated from rain-water.

See page 214.

Smaller sewers suffice.

Advantages obtained.

Duplicate systems costly.

The advocates of land-irrigation recommend as a remedy for the depreciation in value caused by extreme dilution of sewage, the keeping of the domestic or richer sewage separate from the ordinary drainage of the town, either by using the "dry earth" or "pail" methods, or by providing separate systems of sewers. The former methods, while applicable in villages and places with contiguous agricultural land or even—under elaborate management—in towns, is, as has been said, not the best suited for general adoption in crowded localities provided with a regular water-supply. There is much to be said both for and against the duplicate-sewer system. For the sewage alone, conduits may be made only of a size suited for their everyday duty, and not, as in the "common sewer" system, large enough for the maximum flood waters, which may but rarely occur: where pumping is necessary for raising the irrigating-sewage, a much less quantity would have to be raised. The sewers thus reduced would afford much less space as "gas-holders" for storing foul odours, and also would demand very much less water for flushing —a circumstance of particular value in towns not provided with a regular water supply. On the other hand, the duplicate system is much more costly, and there still remains the question of the ultimate disposing of the rain-water with the street impurities. For the street

Sewers cannot take heavy rains.

Rainfall in India. *See also page* 85.

scourings contain the worst of the sewage, especially in towns where house slops are emptied directly or through gullies into the street gutters; the character of such gutter sewage being at its worst during and immediately after dry weather, before heavy rains have flushed the gutters. In tropical climates it is impossible to provide for the heavy rains in the ordinary sewers. A provision for ¼ in. of rain per day is generally considered sufficient in England, but in some parts of India 12 in. of rain will sometimes fall in a day, and even 3 in. in an hour. In cases of this sort the street channels and water courses must be arranged so as to give an uninterrupted flow to the rivers without flooding either streets or houses.

Sewage partially separated.

Leaping-weirs for street drainage.

Advantages obtained.

A compromise between the alternative plans of common and duplicate sewers has been tried with success in some English towns, and where there is an opportunity—as when a new sewerage system is being devised—of suitably arranging the works, it bids fair to be a solution of this particular question. According to this plan, the street gutters are allowed to empty into the common sewers during periods of dry weather and moderate rains, for at such times the gutter-sewage has as much manurial value as the domestic sewage, and for this reason is as ill-suited for free discharge into a river. But at each point of junction with the sewers there is a "leaping weir," so arranged that while a moderate flow from the gutters falls vertically into the common sewer, storm water rushing quickly leaps the weir, and is taken away in a separate conduit. As, when such a time arrives, the streets and gutters will have been already scoured of their worst impurities, the surface drainage may be conducted directly into a river to which the admission of ordinary sewage might be forbidden, and which in a time of flood may be in such a condition from ordinary land drainage, that the street overflow will have no appreciable effect upon it; the common sewers need be (in a climate like England, where provision for rain-water is two-thirds of the whole) but of small capacity; and the richer sewage used for irrigating land is then no longer weakened by dilution, or rendered formidable in bulk for pumping.

Pecuniary results of sewage-irrigation.

The pecuniary results of sewage-irrigation have been almost always unfavourable to the town authorities who have had to get rid of the sewage, for where it is offered for sale, the interests of the farmer and the municipality in regard to the periods or continuance of the sewage-discharge do not accord; while, if the municipality themselves own and till the land, the many difficulties which attend the undertaking (especially under corporate management) hardly ever allow interest to be earned on the capital outlay, and generally result in a deficit. **Expense unavoidable.** Expense in the disposal of sewage must, in short, be looked upon as necessary, in fact, as a tribute paid to health and decency, and in inland towns where no sea or river is available for receiving the crude sewage, nothing remains but to choose from systems *c* and *d* the one which is for the particular case in view the least troublesome and expensive. *See page 216.*

Filtration of sewage through land. Although in the application of crude sewage to land its value as manure has in most cases been considered, the primary or sanitary purpose is the filtering of the sewage through the soil, so that the effluent water which, through the ordinary land drainage, finds its way to the stream, may be sufficiently purified. In many cases the latter purpose is alone attained, and no attempt is made to utilise the sewage as manure. This method may be expedient in cases where the available land is limited in area, and the maximum amount of sewage which the land will absorb and filter, rather than what is needed for vegetation, is the measure of quantity. **Measure of quantity.** There are great differences of opinion amongst engineers, chemists, and sewage farmers, as to the quantity of crude sewage which can, in cases of this sort, be so absorbed or filtered as to render the effluent water harmless enough for discharge into rivers. **Differences of opinion.** It has even been asserted that experiments with the sewage of English towns, show that with an established water supply—all taken with the surface drainage by one common sewer—from four to six gallons of the sewage thus diluted may each twenty-four hours be purified by a cubic yard of soil, according to its kind; so that if an average of five gallons be taken, with soil available to a depth of six feet, one acre (4,840 square yards or 9,680 cubic yards) will suffice for 48,000 gallons; or, assuming 40 gallons per head of population, for the sewage of about 1,200 persons. **Quantity per cubic yard of soil.** But although results like these may be deduced from experiments under favourable circumstances, probably not a fourth part of these quantities could be permanently treated, for the soil would either become choked and unfit for further service, or the effluent be but slightly purified. **Experiments inconclusive.** If, however, the ground be elaborately prepared as a filter bed, and regularly cleansed and renovated, such a method belongs to another category, and must be dealt with accordingly. **Conclusions arrived at.** Summarily it may be said that to effectually purify crude sewage by using it in irrigation, a larger quantity of land is required than is generally to be obtained in the vicinity of large towns; that a smaller quantity of land may be made to suffice if the sewage has already been chemically treated, or if only partial purification, preparatory to a discharge into a sea or tidal river, is in view; and that the combination of methods *c* and *d* is in most cases the best solution of the difficulty. The sewage-irrigation works in the vicinity of Paris afford an example of how a large amount of city sewage can be applied to land, but the example is not one which could often be followed with advantage.

Works at Paris.

(*d*) *The treatment of sewage by Chemicals* has been tried in various ways, some simple and cheap and others complicated and expensive; but the general results, like those of sewage irrigation, have proved that, however necessary and effectual for sanitary purposes, these plans are not successful as sources of profit. The numerous attempts to show profits from such methods have not only proved fallacious, but have done much to discredit chemical treatment altogether. All the chemical processes which have been applied to sewage have for their common object the precipitation of the suspended particles, but they differ very much in the process, and in the further effects which are sought. If in districts remote from habitations sufficient space were available for depositing-tanks, the suspended particles of sewage might be separated without any chemical process, and the earliest and simplest of the chemical methods which is still in use in certain towns—that of treatment by lime—has only the object of precipitating the suspended solid matters more quickly and effectually than by mere subsidence. The lime-treatment has, however, many disadvantages, which render it quite unfit for any but rare and special cases. Lime is so absorbent as to increase greatly in bulk, and it adds to the amount of sludge precipitated; the effluent, though freed from much solid matter, is but slightly purified, and undergoes a further or second decomposition in the river to which it flows; and the residual sludge, which has no saleable value as manure, is a putrescible mud of so offensive a kind that there is great difficulty in getting rid of it. Were it not for this latter circumstance, lime precipitation might be serviceable in some cases, where lime is cheap and other materials dear, as a preliminary to land-filtration, or to the discharge of the effluent into the sea. But unless there is ample waste land immediately adjoining the precipitating-tanks, so that the sludge can be at once buried, the mischiefs of the sewage are intensified in the sludge, and there is no longer the water-carriage for its removal.

Treatment by chemicals.

Chemical methods described.

Precipitation.

Lime-treatment.

Unfit for general use.

Residuum offensive and worthless.

The more elaborate chemical methods are directed towards the

Lime and alum.

Sewage works at Coventry.

Rio de Janeiro.

Method described.

Rio sewage-works.

better purifying of the effluent, and the deodorising of the sludge; the disposal of the latter being the main difficulty. A combination of lime with sulphate of alumina is probably one of the most effectual of the compounds which have been proved by sufficient experience. The effluent from sewage so treated, though apparently pure to sight and smell, contains a certain proportion of soluble matter valuable as manure, so that it is suitable for land-irrigation, and the effluent after being thus filtered may be discharged into rivers without increasing the proportion of impurities which they already carry from the ordinary land drainage. These chemical processes find their best application as preliminary to such filtration, or to discharge into the sea. As instances, Coventry in England and Rio de Janeiro in Brazil may be cited. In the former case, the effluent from the sewage of 40,000 persons, containing a large amount of manufacturing impurities, after the precipitation process and filtration through nine acres of land, flows harmlessly into a small inland river. The sludge is inoffensive, and, as manure, is worth when dry the cost of cartage on to land. The drainage of Rio, which has a population of about 400,000, affords a rare example of works devised and successfully carried out in a large city, previously without any kind of sewers or sanitary arrangements. Situated only a few feet above the sea level, the city is surrounded on three sides by a land-locked bay, having little flow of tide, and the soil was saturated almost to within a foot of the surface. The filth from the houses and streets was emptied at night on the beach; epidemics were of frequent occurrence; and the death-rate was a high one. By the new works every house is drained into the sewers, which carry also a portion of the rain-water (that from the backyards and housetops), and the sewage, after being lifted by steam-pumps, is chemically treated in large precipitating-tanks by lime, alum, and charcoal. There is no land available for after-filtration, but the effluent is passed through a filter of stones and gravel, and flows into the sea. Although the works are situated in the heart of the city, and notwithstanding the absence of a proper water supply, the sewage is so thoroughly deodorised that no nuisance arises from any part of the process, nor from the sludge, which (no agricultural land being available) is deposited on waste land in the vicinity of the city. One important benefit derived from these works is that the level of the water in the hitherto-saturated soil has been lowered. This system has been in operation since 1863 in the city proper, and was afterwards extended to the suburbs. The cost of the process, and of the entire drainage operations, both at Coventry and Rio, does not reach two shillings per head of population per annum, exclusive of interest on capital outlay. In regard to interest, the Rio scheme was established on terms which should be profitable to the capitalist as well as advantageous to the city. But as the drainage-rate levied on the inhabitants is payable in local currency, the great fall in exchange after 1890 reduced the net revenue which could be remitted in gold.

Annual cost.
See also page 230.

See EXCHANGE, *page* 457.

Calcutta drainage works.

In some respects the drainage of Calcutta resembles that of Rio, and the results are even more beneficial. The city is situated on a level only a few feet above the sea, and was formerly so swampy and filthy that fever and cholera were hardly ever absent, and the death-rate was conspicuously high. The alteration and improvements that have been obtained in Calcutta from well-designed sanitary works, carried out under peculiar difficulties, afford one of the most notable instances of benefits so obtained which can be found in modern times.

Elaborate processes.

Profit cannot be obtained.

Sewage sludge fortified by chemicals.

Burnt into cement.
See pages 218 *&* 853.

Still more elaborate chemical processes have in view the giving of an increased value to the sludge as manure, or the more complete purification of the effluent; the former result being sought either as a distinct source of profit, or, as is more often the case, to recoup the outlay for purification. The attempted combination of sanitary purification with a commercial profit has in many cases caused the failure in both respects. If a high standard of purity in the effluent water be demanded, and if it be very difficult or expensive to obtain land for filtration, then the outlay for elaborate chemical processes may be justified; but the most that can then be hoped for is that some of the outlay may be recouped by the sale of the sludge as manure; failure always attending the attempt to earn a surplus profit. By using chemical ingredients which themselves are effectual as fertilisers, the sewage sludge may be converted into artificial manure, the value of which increases in precise ratio (less the expense of waste and error in the process) to the cost of the ingredients used. The higher the value obtained, the greater will be the loss in obtaining it; but it may sometimes be expedient to enrich the sludge to a small extent to induce farmers to take it, and to give it a value which will then bear the expense of carriage. Sewage sludge may be burnt into cement, and where there is a demand for such material, the cost of so treating it may be repaid.

Cost of town drainage.

The *Cost* of town-drainage works must obviously vary within very

Annual expenditure.

Cost of London main-drainage.

Capital outlay on English works.

Annual expenditure.

Garbage. *See page* 217.

wide limits, according to the nature of the works required, and the thoroughness with which they are carried out. The capital outlay has not alone to be considered; and a comparison of the cost of works in various towns is incomplete, unless the annual expenditure for working and maintenance be also reckoned. In a gravitation scheme where the sewage flows directly on to the land, or into a sea or river, the cost for maintenance need be but small; but where pumping-stations are required, or processes of precipitation, deodorising, or other treatment carried on, the annual charges may be considerable. In London, the cost of the main-drainage works and pumping-stations was four millions, or about £1 per head for the population benefited. The annual cost of working and maintenance was in 1880 about 1*s.* per head of population. In England, it may be said generally that the larger number of modern drainage-works have been carried out at some cost between 15*s.* and 25*s.* per head of population; and the annual expenditure in any but ill-managed or peculiarly difficult cases, is some amount between one and two shillings per head, exclusive of interest on capital. This cost does not include the removal of ashpit refuse and garbage.

Provision for future extension.

Rate-income grows with population. *See* RATES, *page* 210.

District arterial sewers.

The expediency of providing for a growth of population must obviously depend upon the probabilities of increase, and the comparative cost—according to the nature of the scheme—of constructing large works at the commencement, or of adding to them afterwards. As in constructing long lines of main sewer it is the intention to intercept all the sewage of the district traversed, it is almost always expedient to allow for a growth of population and increase of houses; the additions to be provided for being measured not only by the water-supply which such additions will carry off, but the additional rainfall or storm-water which new ramifications of sewers will bring into the arterial sewer. But as population increases, so will the area of rateable property, and the capital to be paid off will annually diminish. In some cases, one system of drainage may be made to include numerous towns or villages; the expediency of such a course depending mainly on whether the levels are favourable to lines of arterial sewer and one common outfall. Villages or towns situated along the same valley may be thus conjoined, and provision may be made in the capacity of the main sewer for intercepting the drainage of new districts which may be afterwards added.

Careful surveys necessary.

A proper scheme for town drainage can only be made after careful survey and examination by competent engineers. But to assist an engineer in advising as to the best methods, and contractors in estimating cost, information of the kind described in the following pages must be supplied; and according as the information is full and correct, so probably will the designs and estimates be complete and trustworthy. In few cases, however, will an engineer complete his schemes, or a contractor bind himself to an exact amount, until the conclusions arrived at have been verified at the site. The information needed is as follows:—

Information classified.

Plans and levels.

1. A *Plan* of the town on as large a scale as possible, showing the area to be drained, the main and cross streets, and the lines of houses; and with references to the character of the soil and subsoil at all points. The levels of the different parts of the town as relating to some datum line should be marked on the plan, especially (if there be a river) down-stream; and sections at various places should be given, by which the gradients of the streets and the contour of the slopes may be understood. Upon the plan should be marked the streets, or other lines of route, which are presumably the best suited for the main or arterial sewers. The proposed outfall for the sewer, if in or near the town, should be marked on the plan; but if at some distance, a map (if necessary, on a smaller scale) should be furnished, on which the outfall and routes to it, with their levels and gradients, are indicated.

Route for sewers.

Outfall.

Coast-line.

2. If the *Sea* is available as a receptacle, the coast-line must be shown on the plan, with the places which appear most suitable for the outfall; the slope of the shore at these points, and the nature of the beach and sea-bed, being carefully described. Shoals or banks likely to be affected, or to obstruct the flow of sewage, must also be shown. The different levels of tide should be indicated (including extraordinary tides), the force and direction of prevailing winds and currents, and the direction—as ascertained by floats—which liquid or solid matters discharged into the sea will take during different winds or tides. Any existing sewage-outfalls should be indicated on the plan, and the past general results described.

Tides and currents.

Volumes of rivers.

3. If the sewage is to be discharged into a *River*, information should be given as to the volume of water, and the various levels of tide or flood, in reference to the level of the town or district to be drained; the strength or speed of the current at and for some miles below the town; and whether, and at what places, the river water is taken for drinking purposes. The slopes and material of the banks and river-bed, as shown by cross-sections, should be

See WATER, *page* 205.

furnished, together with particulars of sites suitable for sewer-outfall or pumping stations.

Population.

4. The number of the *Population*, with statistics of the past, present, and probable future rate of increase. The relative density of the population in the different quarters of the town: the approximate total rental value of the houses: the rent generally paid for the different types of houses: and the rateable value of the district to be drained.

Rental value of houses.

Existing methods of drainage.

5. The *Existing methods* of house drainage, and the means used for the removal and disposal of sewage, and for removing refuse from houses, streets, factories, markets, and abattoirs, should be carefully described; and drawings furnished giving in detail examples of one or more types of houses, with their domestic sewage arrangements. A description should be furnished of any manufacturers' or trade refuse which may form part of the sewage to be dealt with. If destruction by Fire is proposed, the following particulars are needed as a basis for a proper scheme:—

Destruction of refuse by fire. *See also page 218.*

The quantity of refuse to be destroyed per day, and a mechanical analysis of it as obtained by sorting and evaporation; whether the estimate is to include buildings and approach roads, or only iron-work that can be exported; whether there is any use by boilers, or otherwise, for the waste heat. If the population exceeds 100,000, the question must be settled as to whether more than one locality is to be furnished with a destructor, and a plan of each available site should be supplied.

Existing sewers described.

6. If *Sewers* already exist they should be described, with their size, shape, and the materials of which they are made; the fall at which they are laid; whether the sewers are ventilated, and if so, how; whether they receive surface water and road grit; whether the presence of road material, such as sand or grit, in the sewer has already caused trouble; whether the town is paved—if so, how, and how much of it; if not paved, the material of which the roads are composed; the stratum of the streets for trenching.

Road paving.

Water-supply. *See Chap. IX.*

7. The nature, amount, and source of the *Water-supply*, and the depth below the surface at which water is reached in the town and in the neighbouring country of lower altitude. If water-works are established, whether the supply is constant or intermittent; and what is the quantity supplied per day for domestic, trade, and municipal purposes. Existing water or gas pipes in the streets should be indicated on the plan of the town. The amount of rainfall at

different seasons of the year should be given if possible, and the maximum known fall in twenty-four hours and in one hour, and full information generally concerning the effect of heavy rains which flood the streets, and for which special provision must be made in the sewers and outfall. If there be dry and rainy seasons, any existing systems of storage should be described.

Rainfall. *See pages 185, 206 & 225.*

8. The immediate *Reasons*—whether injury to health by refuse remaining in close proximity to houses, or the pollution of rivers, or any other causes—which render the proposed new works necessary; and also whether the action of the municipality is voluntary, has been suggested by the inhabitants or by promoters, or has been guided or enforced by legislative enactments.

Reasons for new works.

9. Copies of the *Statutes*, if any, under which the works have been ordered, or under which they must be constructed; and of any present or contemplated bye-laws on sanitary matters.

Laws or statutes.

10. The trades, *Occupations*, and habits of the inhabitants should be described, so far as they may affect any scheme of drainage; whether police or official regulations will be granted to enforce the proper use of new methods; whether conformity to such regulations may be relied on, and the legal remedies which will be available.

Occupations of the people. *See page 54.*

11. If the disposal of the sewage on land is contemplated, the geological formation and the *Nature of the soil* in the vicinity of the town should be described; whether the land is waste or cultivated; whether drained, and if so, at what depth, and to what stream the drainage is taken; the methods of cultivation in vogue; the kind and rotation of crops; the markets at which they are sold, and their value there; whether crops of other kinds which sewage manure would assist would be saleable; the kind and value of the manure which is used; the price at which agricultural or waste land available for sewage operations could be rented or purchased; the tenure upon which it could be held; and any other information by which the possibility and economy of sewage irrigation might be estimated.

Land for irrigation. *See page 185.*

Crops.

Manures.

12. If *Pumping-stations* are contemplated, or artificial methods of filtration and purification, they should be described, the proposed sites indicated, the probable cost or rent stated, and information furnished as to the kind of dwellings and class of inhabitants in the vicinity, and the likelihood of opposition to sewage works on the ground of nuisance.

Pumping stations.

Climate.

13. The nature of the *Climate*, and the extreme temperatures at different seasons, should be described.

Materials and labour.
See page 74.

14. Local information as to labour and building materials available, including those for concrete, the prices at which lime, cement, sulphuric acid (vitriol), sulphate of alumina (or the shale, or clay, from which this can be made), and other agents for sewage precipitation and deodorising could be purchased.

Finance.
See Chaps. II., III.

15. The financial conditions under which it is proposed to construct the works, the periods of payment or terms of concession, and information generally of the kinds already specified.

[*See also* IRRIGATION : RECLAMATION : WATER-WORKS : PUMPING-ENGINES : PIPES : PORTLAND CEMENT.]

CHAPTER XI.

GAS-WORKS.

Growth of revenue.

Gas-works remunerative.

Monopoly profits.

Municipal gas-works.

No undertakings have, in Great Britain, been so constantly remunerative to the capitalist as gas-works, and the growth of revenue has generally been more rapid with a gas undertaking than with water-works, the average rate of dividend paid to investors exceeding that derived from railways or any other public works. As the natural tendency of competition is to reduce the profits of all enterprises to a common level, the maintenance of high profits in gas-works must be explained mainly by the fact that such enterprises have to a large extent had the advantages of a monopoly. So much has this been felt that, up till the year 1880, the instances increased of municipal bodies constructing gas-works or purchasing from companies works already established, with the intention of supplying the gas at cost price; or of earning a profit, and applying it to public purposes. Even since the introduction of electric lighting, well established gas-works offer a similar, though a lessened inducement.

Repayment of loans.

The purchase-money is almost invariably borrowed, and in some instances there is a tendency to spread the periods of repayment over too many years. Although in the case of sanitary works or water-works which will be of permanent advantage to the community, the transference of a large proportion of the burden of repayment to a future generation may be justified, a continuance of the existing system of gas-lighting and manufacture cannot, since the

[See pages 118, 193, 203.

Lenders depend on the security of the rates.

See page 209.

Terms of years for loans.

introduction of electric lighting and in an era of scientific invention, be looked upon as certain. Financial Societies, Insurance Companies, and others who—as well as the Public Loan Commissioners —are the principal lenders of money to municipal bodies, would be indisposed therefore to advance funds for the purchase or construction of gas-works, the revenue from which is put forward by the borrower as a valuable security, were it not that the public rates are also answerable for the debt; and it is the facility for borrowing at a low rate of interest which this latter security affords which is one of the chief inducements to the municipal authorities to borrow. As, however, the public rates have, in many cases, been already deeply pledged for the repayment of loans for sanitary purposes, any failure in the gas undertaking might at a future day press heavily on the community. A shorter term for gas loans than that (generally thirty years) usual for the repayment of other advances, would appear to be the more prudent course, rather than the longer term often asked. The ease with which money is borrowed in England on the security of the rate-income, which—within a very wide range—can be increased till the liabilities be satisfied, must not be taken as a precedent in places where there is no such latent security. The ratepayers borrow cheaply because they run the risk.

Gas-works owned by municipality.

See WATER-WORKS, *page* 193.

Reasons in favour of municipal management.

Reasons against municipal gas-works.

The construction and ownership of gas-works by a municipality cannot be justified by the same arguments as warrant its engaging in such undertakings as water-supply or sanitary works, which, as all important to the health of the community and as interfering with individual rights, may with some advantage be established and controlled on the public behalf. The reasons generally adduced in favour of municipal gas undertakings are—that, as the supply of gas must almost necessarily be a monopoly, it may with advantage be retained in the hands of the authorities; that if the sewers and water pipes are in official hands, so also should be the gas mains; that better and purer gas will be the primary object instead of gain; that the public lighting will be better and more cheaply maintained; and finally, that the profits can be usefully and legitimately applied to public purposes. There is much force in these arguments, but on the other side it may be said that the last three reasons would apply to almost any kind of manufacture; that experience does not recommend the management of manufacturing enterprises by public bodies; and that economy and good management are better assured when stimulated by the watchfulness of private capitalists. It is questionable, therefore, whether the interests of the inhabitants may not be better served by allowing private capitalists to establish and control the gas-works, subject to strict conditions as to the price and quality of the gas, rather than by involving the public revenues in an uncertain or speculative enterprise. Moreover, where a corporation obtains profit from the sale of gas, there is sometimes a tendency to jobbery in the expenditure of the funds; for, so long as the undertaking shows a margin of profit, strict investigation on behalf of the public is neither likely nor easy, and an unnecessarily high price may be maintained. If it becomes usual to look upon the gas profits as a source of revenue, a system of indirect taxation is established, which, whatever its apparent advantages, is in most countries of English origin (though not in towns accustomed to *octroi* duties) the introduction of an entirely new principle in municipal affairs; especially as such taxation is levied not according to wealth or rental, but according to the accident of gas consumption. Where, however, the gas supply of a town is in the hands of two or more companies who are not disposed to amalgamate on terms favourable to the public, the disadvantages of dual management may form a special justification for municipal interference. But as the shareholders in a profitable gas company will demand a compensation beyond the mere return of their capital, the municipality will commence operations under less favourable circumstances than did the original proprietors.

Risk of jobbery.

Gas profits in effect a tax.

OCTROI.
See page 17.

Dual management undesirable.

A plan is adopted in some towns of dividing in equal parts between the shareholders of the gas company and the municipality all profits, after a certain dividend has been paid to the shareholders. This arrangement has for example been applied in Paris, and combines the advantages of private management with profit to the public. The municipality may justify their claim to a share on the plea that it is only a fair return for the monopoly they have granted, especially where they have given also facilities, immunities, or guarantees. This plan is, however, still open to the objection that the surplus revenue so divided ought, with greater justice, to be applied to the reduction of the price of gas to the consumers—a principle which has been satisfactorily applied in London.

Profits divided with municipality.

Surplus profit shared by consumers.
See page 239.

In newly-settled and foreign countries municipalities rarely undertake the establishment of gas-works, although by favourable concessions they encourage private enterprise. Unlike railways and

Foreign gas-works.

other large undertakings, which generally require the combination of many capitalists, gas-works, especially those in towns of moderate size, can in many cases be constructed wholly or in great part by the money of local investors, for whom, indeed, such undertakings are specially suited. But in many foreign towns, although the undertaking is one under their own eyes, the people are not enterprising enough, and outside aid has to be sought to provide some or all of the capital, to design or construct the works, and often to perform all these functions. If there is a competent local engineer, it is sometimes only necessary to import the apparatus, and the works can be carried on without other foreign aid. A contractor will sometimes construct the works for deferred payments; or, with his own money or that of capitalists who assist him, will take upon himself the entire charge and property in the undertaking. In this case, he and those who act with him will generally look for their profit to the transfer of the undertaking when in operation to a joint-stock company; a perfectly proper arrangement, though sometimes such transfers have been discredited by the excessive profits that the price has included. There are many investors who, while unwilling to assist in the earlier and uncertain stages of an enterprise, will join it when they see it earning revenue; and, in such cases, the more venturous contractor will reap a legitimate profit by selling the gas-works to the company at an enhanced price; that is to say, for a sum higher than that for which he would have been willing to execute the works if punctual payments in money had been secured to him during construction. As the ultimate value of the gas-works will depend upon the net revenue they produce, and on the proportion which this bears to the capital invested, the speculative contractors or capitalists who provide the money, will—if they are acting fairly—only do so after assuring themselves that the conditions are such as afford reasonable hope of sufficient profit. In not a few cases, both in England and abroad, gas-works are permanently held by the contractors who made them, and who by themselves, or with their friends, are content to leave their capital thus invested.

Suited for local investors. *See page 22.*

Outside aid required.

Cost defrayed by contractor. *See page 41.*

Sale of gas-works when completed.

Profits gained by sale of works.

Gas-works owned by contractors. *See Chapter II.*

Referring to the various kinds of concessions already described, it may be stated generally that municipalities rarely grant subsidies for gas-works, and almost as rarely guarantee interest on capital, although where gas-works are much wanted, a guarantee may be given for the first two years, or till the works are in operation. The concessionnaires have therefore to be content with the facilities

Guarantees. *See pages 29 & 195.*

or other encouragement afforded them, which may give to the undertaking the advantages of a monopoly, and upon the nature of which the profits and security of the investments will largely depend. Capital once sunk in gas-works cannot be recovered; and those who propose to establish gas-works in a town naturally desire, as some security for their investment and in return for the risks they incur, protection against the competition which might arise if the enterprise should prove profitable. In the public interests, the granting of a monopoly is justified by the peculiar nature of the enterprise, and by the inconvenience which would arise if rival companies were to erect works and dig trenches for pipes in the public streets. It is a usual condition, therefore, that the municipality shall grant a monopoly for a term of years, say from 30 to 80 years, or—if other gas-works be not absolutely prohibited—the exclusive privilege of laying pipes in the public streets during this period. In effect, this exclusive privilege is a monopoly, which if it does not prevent the construction of private gas-works, forbids any competition in the sale of gas to the public. The right of buying up the undertaking at the end of, or during the period of, the concession is sometimes reserved by the municipality; and in such cases it is always desirable that the terms of purchase shall be clearly expressed from the first. But the introduction of electric lighting, with somewhat similar terms of pre-emption, has greatly reduced the value of such a concession.

Facilities granted. *See page* 26.

Monopoly. *See page* 28.

Right of pre-emption by municipality. *See pages* 38 *&* 196.

It is a customary stipulation that the dividends of a gas company shall not exceed a prescribed maximum (in Great Britain generally 10 per cent.); and it is expected that the selling price of the gas shall be kept down to a rate so determined. The obvious interests of the gas company lead them, before reducing their price, to provide amply for the repairs and renewals of their works, and next, to pay to their shareholders (if the law allows it, as in England it generally does) any deficit from the maximum which may have occurred in the dividends of previous years. The interests of the gas company being thus secured, and further profit being unattainable, there is no inducement to an economy in manufacture which will be of benefit only to the consumers. The later legislation for gas undertakings in Great Britain has, however, provided the stimulus of self-interest to such economical management by permitting, for every reduction in the price of gas below a fixed rate, a corresponding addition (according to an agreed scale) to the dividends; while any advance in price beyond the fixed rate involves a diminution in the dividends; the

Prescribed limit to gas profits.

Assured profits not conducive to economy.

British system amended.

Stimulus to economy obtained.

risk to the shareholders of the latter event depending on any rise in the price of coal which may increase the cost of the gas, and largely also on the price obtainable for by-products.

High value of gas shares.

New capital freely offered.

Privilege of investment saleable.

Future profits limited by law.

Sale of new shares by auction.

The profits of shareholders in undertakings where high dividends are allowed being thus practically assured, the value of their shares has risen accordingly; and when an increasing population renders an extension of the gas-works necessary, capitalists are eager to provide more money on similar terms. But as the privilege of thus investing in a profitable enterprise belongs primarily to the existing shareholders, access to such potential profit becomes at once a saleable commodity. While, however, the maximum interest on their original capital may of right belong to the shareholders who invested their money on such a condition, the power of realising in advance, at the expense of future generations of gas consumers, the difference between ordinary and gas-monopoly profits is not so clear; and an equitable adjustment of this question has been found desirable in the public interests. In England, the limitation of dividend on new capital to a lower rate than on the old (generally to 7 per cent. instead of the previously permitted 10 per cent.) has been enacted in some cases, while in others the more stringent condition has been laid down that all new shares shall be sold by auction to the highest bidder; the difference or premium above par value being applied to the cost of works, and not, as before, as a bonus to the original shareholders. This has been effected by supplementary enactments in the case of existing gas companies; and the same principle will probably be embodied in the legislation for new undertakings. In England about 30 per cent of the gross revenue is divided as interest or profit on capital, but this burden, which has been seldom less than one shilling per 1000 ft., tends to diminish, and from 6*d.* to 9*d.* may be anticipated for the future.

Scarcity of capital justifies high profits.

Lapsing of monopoly after term of years.
See page 28.

There may, however, especially in newly-settled countries where capital is scarce, be cases where the chance or expectation of prospective profit on future outlay is the very circumstance which induces capitalists to invest their money; and the inhabitants or authorities may find it impossible to obtain the advantages of gas-lighting on easier terms. This is obviously a question to be decided according to the merits of each case, but should always be decided at the commencement, and embodied in the terms of the concession. The granting of a monopoly for a term of years, at the expiration of which the municipality acquires the property in the undertaking, or the right to demand rent or a share in the profits, is a solution of the difficulty which is afforded by the conditions of many foreign concessions.

Although the inhabitants of a town are left free to purchase the gas or not as they please, it is an almost universal stipulation that the municipality shall pay for gas lamps in the streets; and thus not only is the superiority of the new light exhibited in such a way as to induce imitation, but a certain revenue is secured, which in some cases may in itself ensure a net return on the capital invested: the municipality, who may have refused to guarantee interest, in effect guaranteeing a minimum revenue It is usual to agree in advance for a certain or minimum number of street lamps; and the price may be fixed at a rate per lamp per hour, or per lamp per annum. In the latter case the average hours for lighting should be specified. If the lamps are required every night from sunset to sunrise, the time can be easily calculated and agreed upon; but in some towns economy is sought by extinguishing some or all of the lamps after a certain late hour, while in other cases advantage is taken of moonlight nights to save gas after the rising of the moon. If, as is generally considered convenient in the latter event, the hours and seasons are arranged beforehand from an almanac, the town is frequently left in darkness during cloudy nights. Moreover, economy cannot be obtained proportionate to the quantity of gas so saved, for such variable hours cause more trouble to the lamplighters, while the manufacture and storage of the gas are more expensive because more irregular. A higher rate for gas so supplied may therefore be justified. It is impossible, of course, to give any standard of price for these services in foreign towns, depending as it does primarily on the cost of coal, the expenses of manufacture, and the taxation to which the undertaking is subjected; but the rates agreed upon are generally considerably in excess of what would be paid for a similar supply in England or other places where coal is cheaper, or where a large consumption of gas might be relied on with certainty, or where—as in England—the abundance of capital keeps down to a lower standard than elsewhere the rate of interest which is accepted as sufficient. The price at which gas may be sold to the public may be also agreed upon, but it is generally left to the discretion of the concessionnaires within a certain limit, or with perhaps the stipulation already referred to, that the prices must be lowered when the profits reach a certain point, or that the profits,

Assured revenue from street lamps.

Price for street-lighting, how arranged.

Gas saved on moonlight nights.

Irregular lighting inconvenient.

Price of gas, how determined.

Selling price of gas agreed upon.

See page 239.

after a certain amount has been reached, shall be shared in by the town.

Good quality gas demanded.

Illuminating power of gas.

High quality coal necessary. *See page* 533.

Economy in coal.

Newcastle coal.

Cannel coal.

Residual products. *See page* 250.

Storage of coal. *See page* 533. Export of Coal.

Besides agreeing upon a remunerative price for the gas thus sold to the municipality, there are several other important points for the concessionnaires. Generally, conditions are imposed in regard to the illuminating power and purity of the gas; so determining the kind or quality of coal that must be used, and the cost and trouble of manufacture. The ordinary measure of illuminating power is the number of sperm candles (each candle consuming 120 grains per hour) which gas consumed in a standard burner at the rate of 5 ft. per hour will equal. In English towns the quality of the illumination specified by the municipal authorities for street lamps, and generally defined in the Acts of Parliament by which the Gas Companies derive their powers, varies in different towns from 12 to 20 candles, 14 to 18 candles being the most usual qualities. In gas-works dependent on a foreign supply for all or part of the coal, a high standard of illuminating power renders the maintenance of a sufficient store more than usually important, because, as a certain proportion of high-quality coal is necessary for producing such gas, the supply of suitable coal must be maintained at whatever cost; while, if a lower illuminating power, and therefore coal of an ordinary quality suffice, economy may be often obtained by buying chance cargoes, by waiting to take advantage of low freights, and utilising to a greater extent during such periods local or inferior coal. One ton of Newcastle coal will yield on an average about 9,500 ft. of gas, having an illuminating power of 13 to 14 sperm candles. each consuming 120 grains per hour; leaving as residuum 13½ cwt. of coke and 9 to 10 gallons of tar. One ton of Cannel coal (of average quality) will produce about 12,000 cubic ft. of gas, having an illuminating power—according to the quality of the coal—of from 21 to 27 sperm candles; leaving 11 cwt. of coke (of low quality), and 17 to 20 gallons of tar. In addition, there are the other residual products of breeze and ammoniacal liquor, which are generally saleable at remunerative prices. Almost all kinds of coal deteriorate during a long voyage, especially if through the tropics. In storing coal, about 45 cubic ft. of space per ton is required; the storage space should be covered, and sufficient ventilation provided to prevent spontaneous combustion.

Gas-making burdened by expenses.

Where coal, because of high freights, heavy import duties, or other burdens, is expensive, and the selling price of the gas proportionately enhanced, the new enterprise is, of course, greatly weighted in competition with existing systems of lighting. It must not be supposed that in a foreign town, where gas-lighting has been previously unknown, gas of an inferior quality will suffice; for it is generally the wealthier inhabitants who first adopt the new light, and they may, presumably, have been accustomed to the best kinds of lamps or candles, and will naturally expect a greater degree of brilliancy than that to which they have been accustomed. Moreover, electric lighting offers competing advantages.

Competition with other kinds of lighting.

See page 254.

Standard of purity for gas.

Gas referees.

In regard to the purity of gas, freedom from sulphur and ammonia are the essential conditions, as the presence of these substances renders the gas unhealthy, and hurtful to furniture or pictures. In many large towns official analysts or referees are appointed, who periodically examine the gas: fines or penalties being imposed on the gas company when the degree of purity is below that specified; the tendency of recent years in England having been towards increased stringency in these conditions. When the municipality owns or controls the gas undertaking, and acts also as sanitary authority, the conditions of quality are not always so rigorously maintained.

Onerous conditions.

Gratuitous gas.

Fines.

Onerous conditions in other respects are sometimes imposed on concessionnaires, such as that certain public lamps shall be supplied gratuitously, or at favourably low rates; that fines shall be incurred for stoppages in the supply, or for lamps accidentally extinguished; as well as for non-fulfilment of the conditions just referred to concerning illuminating power and purity. While certain regulations in regard to all these matters are equitable and desirable, promoters of new gas undertakings have in many instances, in their eagerness to acquire concessions or monopolies, agreed to conditions which are obviously too severe, or which have been found afterwards to press unduly on the enterprise. No proper estimate can be formed of the value of a concession without a knowledge of what is or will be demanded by the authorities on these points. Not only in regard to the conditions, but in the manner of enforcing them, is caution necessary. Sometimes the imposition of fines, and the settlement of questions arising out of the concessions, are left to some government or municipal official, who may be ignorant or partial. It is important that the decision, either in the first instance, or at any rate on appeal, should lie with a qualified and impartial tribunal, able and willing to enforce its decisions; and that a similar authority shall adjudicate on the claims for payment for gas

Conditions, how enforced.

See Bye-Laws, pages 198 *&* 218.

Impartial tribunals.

See pages 24 *&* 54.

supplied, for theft of gas, or on other matters, as required by the concessionnaires.

Profit from extra works.
See also page 198.

Bye-laws.

See also page 158.

Stipulations may be made securing to the concessionnaires the monopoly of private extra works, such as those necessary for making connections to the mains, and laying of branch pipes into the houses, the supply of meters, and in some cases of house fittings, Certain necessary privileges, also, must be conferred upon the concessionnaires or gas company, such as the right of way for pipes, the right of excavating in the streets, and, with certain qualifications, the right of entering houses in which gas is consumed. In England, the Acts of Parliament by which gas-works are established authorise bye-laws for preventing misuse or theft of gas, and for protecting the apparatus and other property of the gas company. It is equally, or even more, important in countries where there is no precedent for such bye-laws that the necessary regulations shall be agreed upon beforehand, and embodied in the concession or enactments under which the gas undertaking is established.

Consumption of gas.

Capacity of works, how determined.

Extension of works provided for.
See also page 202.

The quantity of gas consumed in any town depends not only on the population, but on the wealth, habits, and occupations of the people. In estimating the quantity of gas which will be required, so as to decide what capacity for manufacturing and storing will be necessary, the ordinary consumption must not be considered, but the extraordinary or exceptional consumption, such as for illuminations and for times of festivals, although during such periods the ordinary consumption may be partially suspended. Moreover, as the population of a town grows, or as the demand becomes greater, more gas will be consumed; and as time is required for extending the works, they should not only be arranged at the beginning with a view to after extension, but the manufacturing capacity at any time should always be in advance of the demand.

Consumption per head of population.

In order to establish a basis of computation for towns of different sizes, it is necessary to assume a certain rate of consumption. If the towns in Great Britain where gas is used were tabulated according to the population of each within the area supplied with gas, the extreme minimum and maximum quantities consumed per annum would—if very exceptional cases be omitted—probably be about 1500 and 3000 ft. per head of population. In London the consumption has attained to 4000 ft.: there being always a tendency in capital cities to later hours and greater consumption than in provincial towns. A mean between the ordinary extremes gives

Consumption less in foreign countries.

about 2200 ft. per head; but as in foreign countries where gas is first introduced the consumption is generally less than in English towns, 1500 ft. and—as is often the case in newly-settled countries where much of the population is of an inferior race—even 1000 ft. may be taken as a more probable estimate. There is also the risk that at some future time electric lighting may diminish the demand for gas, the likelihood of this depending greatly on the price of gas.

New uses for gas.

But while the introduction of electric lighting has restricted the increase in the demand for gas, there is not likely to be an actual decrease in the consumption for some time. The growing use of gas as fuel for heating purposes, for cooking and for gas engines, tends to a growing consumption, and in London and other cities the gas companies encourage such use of gas by supplying the necessary apparatus at rental rates. Even where electric lighting has been adopted, gas engines are often used for driving the dynamo.

See also page 481. PRODUCER-GAS.

Average hours for gas-lighting.

Where street lamps burn all night, as in London, the minimum and maximum number of hours in summer and winter may be taken as 6 hours and 14 hours, or an average of 10 hours, though in certain climates, times of fog occasionally derange previous calculations. The average consumption in private houses, factories, and public buildings is generally estimated at 4 hours per day; and as the gas is not usually consumed after midnight, the difference between summer and winter is much greater than with public lamps. Gas-works in any towns to be equal to the demand must, as already stated, be capable of producing every 24 hours the extreme winter rate of consumption. Thus, if in a town of 5000 inhabitants 10 million cubic feet per annum be consumed, the works must be equal to supplying daily not less than $\frac{1}{365}$th part of this, or, say, 28,000 ft., but if a reserve power for exceptional occasions be needed, probably double that quantity, or 56,000 ft. The cost of foreign gas-works may be calculated in England more nearly than that of the other undertakings referred to in preceding chapters, because it depends less upon local circumstances; the apparatus and works necessary for a certain number of lights being (subject to certain circumstances of locality) almost the same everywhere.

Summer and winter consumption. *See* LATITUDE, *page* 248.

Cost of gas-works.

It may be said that the progress in the art of gas-making has not equalled that of other applied sciences; and the inertness has been mainly owing to the monopoly which gas enterprises have in the past enjoyed, and to the consequent lack of that stimulus which free competition alone provides. Notwithstanding this comparative

New inventions, and improvements.

backwardness, there have been many ingenious inventions connected with the apparatus of gas-works, such as the charging and drawing retorts by machinery, the firing of retorts with gas instead of coal, and, by inclined retorts, facilitating greatly the charging. Better and purer gas can now be made with less wear and tear of plant, and with a less consumption of coal, than were formerly necessary for impure gas. The introduction of electric lighting has greatly stimulated such improvements. Incandescent gas-mantles afford a more brilliant light both for streets and houses than was formerly attainable, and these compete with electric glow-lamps. On the other hand, owing to the increased expense of materials and labour, the cost of making gas has in some respects become greater.

Cost of foreign gas-works.

The cost of gas-works in foreign countries is, of course, greater than in England in proportion to the distance, the expenses of carrying the apparatus, the extra cost of erecting buildings, and other circumstances; the following being the principal incidents which must be taken into account in any estimate based upon precedent or fixed standards:—

Incidents of cost enumerated.

a. The cost and tenure of land for the works.

b. The nature of the soil.

c. The climate.

d. The area of the district in proportion to the number of houses.

e. The cost of building materials and labour.

f. The expenses of management.

g. The latitude, by which variations in the length of days are determined.

h. Freight, import duties, and taxes.

The above points may be elucidated as follows:—

Site for gas-works.

a. It is not always easy to obtain on suitable terms a *Site* which will combine all the advantages desired: these being—sufficient area for the works and room for extension; a shape which will allow of a convenient and economical disposition of the buildings (great irregularity, or a shape very narrow in proportion to length, is undesirable); facility for delivering coal, and for despatching coke and other products; a low level, from which the gas can ascend to the other parts of the town; a central position, so far as the other conditions will allow, this latter being of more importance than the low level.

Local dislike to gas-works.

The unwillingness of the inhabitants, especially the wealthier classes, on the score of nuisance, to have the gas-works in their neighbourhood, also often limits the choice of site.

Nature of soil.

b. Upon the nature of the soil the kind and cost of the *Foundations* will depend—points of great importance in regard to the gas-holder tanks, and, in a lesser degree, to all the other buildings. If the soil be very hard clay or rock free from fissures, a tank simply excavated and unlined may be sufficient; but in the great majority of cases the pit has to be lined with masonry, brickwork, or concrete. The use of concrete only, instead of brickwork, has not hitherto been very successful. Considerable expense is sometimes incurred in obtaining suitable puddle clay for forming a water-tight lining. If the soil be very loose or wet, iron tanks become necessary; and to this expense has sometimes to be added the cost of pumping during the excavating and building, or of piles driven into the ground to make a sufficiently firm base for the foundations. On sites situated on the low-lying banks of a river or sea, or on very marshy land, even iron tanks cannot easily be sunk below the soil, and it becomes necessary to build the tanks entirely above the ground level. The cost of the retort settings and of the various buildings is also dependent to a large extent on the nature of the soil and the foundations.

Gas-holder tanks.

Foundations sometimes very expensive.

Climate.

c. Extreme *Climates* render special precautions necessary. In countries exposed to high winds, or heavy falls of snow, the gas-holders and the roofs of the buildings must be made correspondingly strong; in cold climates the gas-holders and other parts of the apparatus usually in England left open to the air, are generally entirely enclosed in buildings, pipes and other parts being also protected from frost; in hot climates, arrangements have to be made for keeping cool the gas-holders, and for extra ventilation in the various houses.

Extremes of temperature.

Area of district to be lighted.

d. The *Area* of the district as compared with the number of houses determines the quantity of pipes necessary for a certain sale of gas; and where small outlying districts or suburbs have to be served, especially where the number of consumers is at first small, the cost of pipes increases the capital outlay without much return in revenue. In English towns the population per mile of main ranges from 1000 to 3000.

Population per mile of main.

Building materials.
See also page 74.

e. The cost of building *Materials* varies very much in different countries; and in many towns where gas-works have been established by foreign capitalists there is neither brick, stone, nor timber available; and these materials, or ironwork as a more convenient substitute, have at considerable extra expense to be imported.

The difficulty of obtaining suitable workmen has also often to be encountered.

Expenses of management.

f. The expenses of *Management* in foreign gas-works are often very great, especially where skilled superintendents have to be sent from a distance, and such charges tell heavily on a small revenue.

Latitude determines length of daylight.

g. In the latitudes near the equator the *Lengths of days* approximate more nearly in winter and summer than in countries outside the tropics, and this circumstance tends to economy in the expenditure of capital. For as it is necessary in constructing gas-works to provide for the maximum consumption of the longest nights, much of the manufacturing and storage capacity of works situated in latitudes where the length of days varies much with the seasons, is idle and profitless during the summer.

Freight and insurance. *See page 447.*

h. Freight and insurance add considerably to the cost of apparatus imported; and, for towns not situated on the coast or on navigable rivers, the cost of inland carriage, especially if the coal has also to be imported, sometimes forbids altogether the profitable erection of gas-works. To these unavoidable expenses are often added high import duties on iron and machinery. In such cases the undertaking is greatly weighted in competition with other and previously existing methods of lighting, and the cost of gas to the inhabitants is of course enhanced. The privilege of importing material free of duty is often sought by concessionnaires, but except in the case of capital cities is not granted so readily for gas-works as for such undertakings as railways and harbours, which may be considered as of more national importance.

Import duties.

Immunity from duty allowed. *See page 97.*

Variable cost of gas-works.

It has been seen from the foregoing pages that any estimate of the cost of gas-works in a foreign country depends upon many variable circumstances, and therefore that even an approximate statement of cost must in regard to these circumstances be based upon certain conjectural assumptions. The capital outlay in connection with gas-works, including mains, ranges in England from 10*s.* to 16*s.* per 1000 ft. of gas-manufacturing capacity per annum; though in large cities like London and Paris, the rates sometimes rises to 20*s.* Or, to take another measure of value, the cost of gas-works ranges from £4 to £7 per ton of coal-carbonising capacity per annum, or, in the exceptional cases above referred to, may be as much as £9. The capital outlay expressed by the higher of these rates includes considerable expenses for Parliamentary contests, compensations, and

Approximate cost of gas-works.

the somewhat wasteful expenditure in construction at a time when the science of gas manufacture was not well understood. By gradually modernising the plant out of revenue as the production grows, the output capacity in proportion to the capital outlay may be increased.

Passage of gas through pipes.

See PIPES, *page* 644.

The quantity of gas which can be discharged per hour through a pipe of a certain diameter depends upon the pressure of the gas and upon the length of the mains. As the friction increases with the length, the diameter of the pipe must be increased where the mains extend far; and to afford a basis for an approximate estimate, it is necessary to assume a certain pressure, which as an ordinary average, may be taken as equal to that of a column of water 1½ in. high.

Cost of lamp-pillars.

Ordinary street lamp-pillars, complete with lamps and pipes, cost from £2 10*s.* each upwards, those suitable for the principal streets of a city costing £5; large pillars with groups of lamps cost from £12 to £50 each. Each street lamp with one burner consumes from 4 to 5 cubic ft. per hour, and the same consumption may be assumed for private burners.

Cost of works per head of population.

In Great Britain the cost of gas-works, including mains, averages from 15*s.* to 25*s.* per head of population, the lower rate being for towns of very small size. In the case of very large cities, where works of extraordinary magnitude are constructed, the higher figure is sometimes much exceeded. Gas apparatus on a small scale, for supplying mansions, factories, or villages, is made in England, especially for export; the capacity of such apparatus being stated according to the number of lights which it can supply for a certain number of hours per day; but the proportions which the storage bears to the manufacturing capacity can be arranged to suit particular cases. A complete apparatus for supplying 200 burners for four hours daily, and including necessary fire bricks, costs from £200 to £250, and weighs about twelve tons. An apparatus for supplying double the above quantity would cost about £400, the price per unit of supply gradually diminishing as the size increases. For any number of lights beyond 500 it is seldom expedient to export an apparatus, unless it has been designed on purpose to meet the necessities of the particular case.

Cost according to quantity.

Apparatus for making oil-gas.

See also pages 253 *&* 600.

Special apparatus for manufacturing gas from oils, petroleum, &c., is also made on a small scale, the prices ranging from £50 for an apparatus sufficient for 50 lights, to £1000 for one sufficient for 2000 lights: the weight for shipment ranging from 2 to 30 tons.

Profits depend on good management.

The *Profits* of any gas-works obviously depend not only upon the capital outlay, the cost of coals, and the selling price of the gas and residual products, but upon the skill in management; though this fact has not had its logical outcome in those towns—numerous in England—where the advantages of a monopoly, and the absence of an authoritative limit to price, allow the gas company to recoup themselves by high charges for an unnecessarily high cost of manufacture. The current expenditure depends primarily upon the skill with which the works have been designed in the first instance, so as to allow the various processes to be carried on with the minimum of labour. Simplicity should be studied in the design of the buildings; and, in foreign countries, both in the arrangement of the apparatus and the order of procedure, economy will be attained by conforming as far as possible to the habits and capabilities of the native workmen.

Skill in design necessary.

Economy in manufacture.

Cost of gas-making.

In Great Britain, the expenses of manufacture, distribution, management, and maintenance of the works, exclusive of the cost of coal and of interest on the capital invested, and without taking credit for the revenue from coke, tar, and other residual products, ranges from 1*s.* to 2*s.* per 1000 cubic ft., and, including coal and all charges, about 70 per cent. of the gross revenue is needed to defray the cost. The cost of the gas itself in any particular case depends primarily upon the cost of coal. But as the cheapest kind of gas for use as fuel in steel making and other metallurgical operations is made by private persons at as low as from 1*d.* to 4*d.* per 1000 ft.—though such gas is cheap, because a high degree of purity and illuminating power is not required—the experience so gained points the way to further economy in gas for lighting. In England, the selling-price of gas varies from 1*s.* 9*d.* to 7*s.* per 1000 cubic ft., according to locality and the current price of coal; and these rates generally allow ample profit to the makers. In foreign gas-works established by British enterprise, the prices range from 5*s.* to 20*s.* per 1000 ft. In cases where the higher of these rates are in force, not only has all the apparatus generally been imported, but the whole of the coal has to be imported at very great cost.

Selling-price of gas.

Value of residual products.
See COKE, *page* 535.

The value of the residual products varies greatly in different localities. The price obtainable for coke depends on the current prices for other kinds of fuel. Modern improvements in the mode of removing ammonia from the gas have added to the profit from this source, while also the demand for ammoniacal liquor and tar has grown in large cities, where the quantity produced is sufficient to induce the erection of special manufactories for utilising them. Where coal is cheap it is often difficult to sell gas-coke at any price, and it is sometimes given away. Tar also has frequently a very low selling value, and especially so where by skill in gas-making the illuminating constituents of the gas are prevented from being taken by the tar. Where this is effected the illuminating power of the gas may be obtained with the least amount of Cannel or other high-priced coal, while the tar thus reduced in value to tar-distillers can be profitably used as fuel at the gas-works. Many new uses have, however, been found for the residual products, and in England from 50 to 70 per cent. of the cost of the coal is recovered. Indeed, the revenue from such sales expresses very nearly the net profits of the entire undertaking, and were it not for the expenses of distribution and management, gas could probably be sold in England at 1*s.* per 1000 ft., if made with every modern advantage on a large scale.

Value of tar.

Tar as fuel.

To arrive at the profits of gas-works—after the cost of works, coal, and manufacture has been reckoned—the waste must also be taken into account. In the greater number of English gas-works, the amount of gas unaccounted for varies from 8 to 15 per cent. of the total quantity manufactured; but by increased care in laying and jointing the pipes, the loss has in the best-managed works been brought as low as 4 per cent. It will be seen that the difference which these limits express—and which represent degrees of skill in management—is in itself sufficient to pay a fair interest on capital.

Waste of gas.

Leakage.

Gas-works have in Great Britain been looked upon by investors as permanent undertakings, for even where the local authorities have the option of purchase, it has generally been upon terms which will return to those who provided the capital a compensation based upon the current revenue. But if profits diminish, because of electric lighting or other competition, the shares in gas companies may lessen greatly in value. The question is likely to arise whether some form of reserve or sinking fund should not be established out of annual profits to provide for the time when the undertaking has ceased to be profitable.

Sinking fund.
See page 39.

For Designing the works and apparatus necessary for supplying a town with gas, the following information is required; and, the scheme having been prepared, the cost of establishing the works and making the gas can be ascertained. On the basis of such estimates

Information for designing new works.

of cost, and with the following information before them, contractors or capitalists can form an opinion as to the probable profits of the enterprise.

Particulars classified.

Plan of town.

1. A *Plan* of the town, with the names of the streets and the lines of the pipes marked upon it, with a key or explanatory list describing which are the principal streets and public buildings, and the proposed site for gas-works. The different levels of the town should be marked with reference to some datum.

Levels.

Population.

2. The *Population* of the town; the past and probable future rate of increase in the population; a classified list of the number, kind, and value of the houses; the avocations and customs of the people; the price charged for electric or other systems of lighting in the streets and houses; the likelihood of gas being saleable for heating or cooking; and any other information by which the probable consumption of the gas may be estimated.

Probable consumption of gas.

3. The experience of gas-works in neighbouring towns, or in other places where the circumstances are similar.

Kind of coal obtainable.

4. If *Coal* exists in the country, its suitability for gas-making should be minutely described, samples furnished, its cost at the mines stated, and the means and cost of transport to the gas-works described; together with the means and cost of landing imported coal, and conveying it to the gas-works.

Transport.

Dues and taxes.

5. The import *Duty*, *Taxes*, or imposts to which the apparatus, coal, or the revenue or profit may be liable.

Cost of land.

6. The cost of *Land* on which to build the works, and the terms or tenure on which the land can be held, and whether there is any likelihood of objection from the inhabitants on the score of nuisance. The nature of the water supply and its cost.

Water supply. *See Chapter IX.*

Nature of soil for foundations.

7. Precise information as to the nature of *the Ground* on which the works are to be built—whether rock, sand, or clay; whether firm or yielding, wet or dry; the depth at which water is reached; this being ascertainable with certainty either by trial pits or probings.

Building materials.

8. The cost of *Building Materials*, including those for roof covering; the kind of workmen obtainable, and their rates of wages; the quality and cost of clay for puddling the gas-holder tanks, or lime for purifying the gas; also whether suitable stone or brick buildings can be erected at moderate cost, or whether it would be better to import bricks or iron framework for buildings. The materials with which the streets are made and paved should be described, together with the drains or water pipes in the streets, and the depth at which

Kind of street paving.

water would be met in trenching; whether canals or streams will have to be crossed by the mains, and any other information which may affect the method and cost of laying gas pipes.

Laying of pipes.

9. The kind of *Fuel* in use in the town for domestic or manufacturing purposes, its cost, its abundance, or otherwise, and any other information by which the probable demand for and the selling value of coke may be estimated; so, also, any outlet which may be reckoned on for the sale of the other residual products.

Value of fuel.

Probable demand for coke.

10. If coal for gas-making cannot be brought to the site at a sufficiently moderate price, any other available *Materials* for gas making—such as resin, resinous wood, naphtha, oil, or petroleum—should be described, together with the cost, the sources of supply, and the cost of transport.

Materials for gas-making—oil, resin, naphtha.

11. The nature of the *Climate* should be described, not only for its effect on labour and materials, but because, as already mentioned, the designs for the buildings and apparatus for a gas factory are in many ways determined by the information on this point.

Climate.
See also page 74.

12. The *Terms* of the concession granted by the municipality, or which may be reasonably expected, should be stated fully, with special reference to the following points: the nature of the monopoly, the length of term, the engagements which have been made for supplying lamps in the public streets, the subsidy or guarantee or facilities which are to be granted, and the obligations which are to be enforced on the concessionnaires.

Terms of concession.
See pages 18 *to* 56.

13. The fluctuations in the *Rate of Exchange* which—as judged from the experience in the past—are likely to occur. If coal has to be procured from a foreign country at its intrinsic value while the payments for gas are made in depreciated currency, the revenue—if measured in British sterling—will be much diminished.

Rate of exchange.
See page 455.

[*See also* CONCESSIONS: WATERWORKS: ELECTRIC LIGHTING: THE ESTABLISHMENT OF FACTORIES: COAL: PIPES: IRON ROOFS AND BUILDINGS.]

CHAPTER XII.

ELECTRIC LIGHTING.

Batteries.

ELECTRIC Lighting by the incandescence of electric conductors was known many years before there was any idea of using it for practical purposes. For so long as the electric current could be produced only by the consumption of zinc in a battery, lighting by such means was too expensive for anything but a laboratory experiment. It was only after the discovery based on Faraday's researches that electricity could be produced by an expenditure of motive force—as from a steam engine, gas engine, or water wheel—at a cost less than one-fiftieth of that from a battery, and, after numerous subsequent inventions, that the use of electricity for lighting, as well as for the transmission of power, became possible. The machines by which the electric energy is produced are usually known as dynamo-electric generators, or, shortly, as dynamos; and, although there are numerous shapes, arrangements and combinations, which have formed the subject of as many inventions and patents, the common principle of them all is, that mechanical power, being applied to rotate an electric conductor, forming a closed circuit in a magnetic field produced by powerful magnets, the original energy of the motor is transmuted into electricity, which can be transmitted by wire or other conductor, and given out at will, either

Faraday's discoveries.

Dynamo generators.

as heat to produce an incandescent light or reconverted into mechanical energy.

Resistance causes heat.

If, in the course of transmission, a current of electricity meets with resistance it generates heat; and though in the ordinary conductors this resistance should be very small, and the consequent heat imperceptible, in extreme cases the heat may, owing to insufficiency in the size of the conductor, cause it to become red-hot or even fuse it. But the heated conductor, when properly controlled and enclosed, forms an incandescent or glow lamp. If the conductor be cut, the current will pass over the gap, if of moderate width; and air being a bad conductor, the resistance and consequent heat produces light. If the ends of the conductor are of carbon they become white-hot or incandescent, producing with the arc a brilliant light as they burn away. This is the principle of the arc lamp.

Incandescence. *See page 261.*

Arc lamps.

Before referring further to the different methods of lighting, it may be convenient to define the various electrical units that have been established, and which are by universal agreement accepted as standard units in all countries, and also to define some of the usual designations of method and arrangement. When two plates of dissimilar substances, such as zinc and copper, are immersed in diluted sulphuric acid or other chemical solution (as in a primary battery), or when a piece of wire or other conductor is moved through a magnetic field (as in a dynamo), an electro-motive force is set up between the plates or in the wire. This E.M.F. indicates the power of doing work, or, in other words, the presence of stored-up energy. When, to continue the above illustration, the two plates in a battery are joined by a wire, or the two ends of the wire in a dynamo are joined, the E.M.F.—designated sometimes also as "difference of potential" or electric pressure—causes a current to flow through the wire and through the cell (or dynamos as the case may .be), the whole forming what is known as an electric circuit. The volume of the current depends on the amount of resistance the entire electric circuit offers to the E.M.F. which the chemical in the battery (or the dynamo) can sustain. As analogous, and as an illustration, if a raised tank containing water be connected to a lower tank by a long pipe, the difference of level produces a pressure, and water flows from the upper to the lower tank; the quantity or volume passing in any given time depending on the resistance offered by the pipe. A large pipe affords small resistance, a constricted pipe large resistance. Similarly, for low-pressure electric currents, conductors

Electrical units defined.

Electro-motive force (E. M. F.).

Potential.

Analogy of water pressure.

Sufficiency of conductors. *See page 264.*

of large sectional area are necessary, whereas smaller conductors may be used when the pressure is greater. In either case the resistance increases with the length of transmission.

Volts.
Amperes.
Ohms.
Watts.
Kilowatts. *See page 568.* HORSE-POWER.
Board of Trade unit.
Kilowatt hours.

The electric unit of pressure is termed the Volt; the unit of rate, volume or current is termed the Ampere; and the unit of resistance the Ohm. These have a definite relation to each other, whatever may be their actual magnitude, which is expressed by the equation $C = \frac{E}{R}$, when C is the current between any two places, E the pressure, and R the resistance between those same places. This is known as Ohm's law. The electrical energy conveyed along a wire, or supplied to lamps or motors, at any given time is ascertained by multiplying the volts by the amperes, the product (C E) being expressed in terms of another unit, the Watt, the unit of rate of work—e.g. 50 volts × 10 amperes = 500 watts, or 100 volts × 5 amperes = 500 watts. A kilowatt is simply 1000 watts, and is the unit generally used to express the size or capacity of electrical machinery. An electrical horse-power is 746 watts—i.e. if a motor could be made to return 100 per cent. of the energy put into it, 746 watts would be required to produce every horse-power of useful work. In Great Britain, what is known as "Board of Trade Unit" is the supply of 1000 watts for one hour, and the electric current is generally sold to users at a price per Board of Trade unit. In other words the kilowatt hour, or Board of Trade unit of electric energy is the quantity of energy supplied in one hour by a current at such a pressure that the product of volts, amperes and hours amounts to 1000. Thus, a current of 10 amperes at 100 volts for one hour is a B.O. Trade unit, or a current of 4 amperes at 500 volts for ½ hour is a B.O. Trade unit. A simpler designation will probably be found. Since the fall of pressure in the conductor depends on the number of amperes, or rate of flow, and since to transmit a given number of watts (or C E) the amperes may be reduced as the voltage is increased, it follows that high voltage is advantageous for long distances. Transmission at a low voltage becomes expensive for any but a short distance, because the conductor must be relatively large, and the copper of which electric conductors are made is an expensive metal. Up to a distance of, say, 800 yards the necessity for high pressure seldom arises; it is frequently disregarded up to one mile, but beyond that distance economy must be obtained by the use of high pressure, which presents certain inconveniences and, when the pressure is great, even dangers.

High and low pressure. *See pages 266 & 270.*

Although the tension or pressure deemed most suitable for incandescent lighting has been from 50 to 100 volts (and at a later date up to 230 volts), and within these ranges there is neither danger nor inconvenience, much higher pressures may be used for certain forms of lighting. For arc lighting, pressures of from 400 to 2000 volts are frequently employed. The economy obtained by transmitting the electric current at a high voltage is dealt with elsewhere; the skill of the engineer is exercised in each case as it arises, to judge between methods available; and the decision on this point is a preliminary which often forms the keynote of the whole project.

See TRANSMISSION OF POWER, *page* 505.

Positive and negative conductors.

The terms "positive" and "negative" are used to distinguish between the two conductor wires leading from a dynamo or battery, and originally signified that the positive wire was the point of highest pressure, and the negative of the lowest pressure; the flow of the electricity, therefore, taking place from positive to negative in the external circuit. It is now recognised, however, that it is not known whether any flow at all, in the ordinary sense of the word, takes place. But certain definite effects are obtained at either pole, and the terms are convenient.

Direct or alternating currents.

A current of electricity produced from a generator may be either "direct" or "alternating." A machine producing a direct or continuous current is usually called a direct-current dynamo, or shortly a "dynamo," and a machine producing an alternating current an alternating-current dynamo. In a direct-current dynamo the armature coils are connected to a commutator, upon which the "brushes" or "collectors" rub in such a manner that the flow is always in one direction. In some forms of alternator the armature revolves, and the armature coils are usually brought to two metal rings, upon which the brushes rub and the current alternates; a current in one direction being followed immediately by a current in the reverse direction. In others the field magnets revolve, and the armature being stationary no rubbing contacts are needed for the main circuit. The alternations (or "periods" or "phases") are generally very rapid, i.e. from 25 to 150 alternations per second. The alternating current has very little magnetising effect, and alternators require to have their field magnets excited by a small continuous-current dynamo, commonly called the "exciter."

Rapid alternations.

Generators, motors, lamps, and other electrical apparatus, may be connected up in three ways, i.e. either in "parallel" or in "series," or by the 3-wire (or 5-wire) system. There are several other methods of connecting in combination of parallel and series, but these have only a theoretical interest. It is beyond the present purpose to describe in detail the differences between these terms, or to set forth the many and diverse circumstances which must determine the choice of method in particular cases. Shortly, it may be said that if the generators are coupled up in parallel they must supply electricity at the same pressure, and then all the positive brushes are connected together, and all the negative brushes also. In this manner the total effect produced is the pressure of one machine multiplied by the sum of the currents of all the machines together. Connecting in series is the coupling of the positive brush of the first machine to the negative of the next, and so on all through the series, a positive brush being left free at one end, and a negative at the other. In this case the machines have all to generate the same current, and the total effect produced is the current of one machine multiplied by the sum of the pressures of all the machines. In such an arrangement of lamps in series the whole current passes through each lamp; consequently, the voltage of the circuit is the voltage of each lamp multiplied by the number of lamps. On the other hand, in a multiple arrangement, the electromotive force of one lamp will be that of the number of lamps multiplied by the current of each. As will presently be explained, arc lamps are generally run in series, and glow lamps in parallel.

Coupling in parallel.

Connecting in series.

Explanatory analogy.

It is often attempted to illustrate or explain by the analogy of earlier and more familiar methods of power transmission, the manner in which electric energy may be conveyed and distributed. The following are instances of such analogies as applied to the three systems of connecting up just described.

By energy of horses.

When two horses are abreast they may be said to be pulling "in multiple" or "in parallel." When two locomotives are pulling tandem they would be "in series." One hundred water-wheels may be driven on the same level or "in parallel" by 1000 gallons of water falling 10 feet in a given time, or one below another by 10 gallons falling 1000 feet. "In parallel" there is a general race-way 10 feet above level large enough to pass 1000 gallons in a given time, from which a different 10 gallons goes through each wheel; "in series" there is a small pipe only large enough to pass 10 gallons, and the same 10 gallons of water starting 1000 feet above level, goes through all the wheels in turn. The water-power is the same.

Falling water.

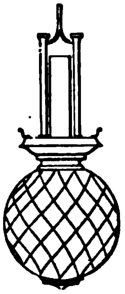
Street lighting.

An arc lamp for street lighting requires about 500 watts electric power, or 10 amperes at 50 volts each. One hundred lamps may be supplied from 1000 amperes of current at 50 volts "low tension" in parallel, or from 10 amperes at 5000 volts "high tension" in series. A standard 16-candle-power incandescent lamp requires about 60 watts. The usual house lamps are arranged in parallel, and for this consumption of 60 watts 1 ampere may be taken at 60 volts, or $\frac{3}{5}$ of ampere at 100 volts, or $\frac{1}{3}$ of an ampere at 200 volts. The actual voltage adopted is determined by that of the available supply. The amount of power and cost for energy are the same, whether the current is of large amperage at low voltage, or of small amperage at high voltage. The 3-wire method, which is most largely used for low tension distribution, has a middle or neutral third wire, and—continuing the same analogy of water-power—is like a race-way at ground level, above which is a set of upper water-wheels supplied from a pipe (the positive wire) 10 feet above, and below is another set through which water falls to a pipe (the negative wire) 10 feet below level. The 5-wire system is arranged on the same principle.

House lamps.

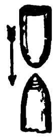
3-wire system.

Arc lamps described.



57.

Carbons.



58.

Electric lamps are of two principal kinds, known as Arc lamps and Incandescent or glow lamps. In the arc lamps there are two carbon sticks or pencils, each forming the end of a wire conductor, the electricity passing along the one carbon, called the positive, to the other, termed the negative carbon. The incandescence takes place, as already described, between the points of the carbons as the current passes from one to the other to complete the electric circuit. As it is necessary, in order to obtain a steady light, that the gap between the carbons shall be uniformly maintained, some mechanism has to be arranged to move them towards each other as they are consumed. There are various means of doing this, clutches, springs, levers, or clockwork, controlled by the electric current itself, being employed in different ways, and forming the subject of numerous patents. In order to soften and diffuse the light, and to arrest the sparks that fall from the burning carbons, it is usual to enclose the lamp in an opalescent or ground-glass globe. Arc lamps of this sort are made of all capacities from 200 to 10,000 candles, but the great majority have an illuminating power of between 1000 and 2000 candles. Allowing for loss in the transmutation of forces into electric energy, about one effective horse-power is required for one 1000-candle lamp taking 10 amperes; but larger lamps can be more economically supplied, and under such circumstances it is generally considered that 2 candle-power is given for every watt consumed.

Lighting power of arc lamps.

The nominal lighting capacity of arc lamps as given above is measured in a conventional manner, and exceeds that which is effectively diffused. The cost of electric arc lamps depends, as in the case of gas and other lamps, a good deal on the style and ornament as well as on the system. Thus, a 1000 to 2000-candle lamp will range in price from £5 to £10. The pair of carbons for each lamp cost from 2*d.* to 6*d.*, and last, according to their kind, from 8 to 30 hours. But enclosed arc lamps are made to last 250 hours. The cost of labour in replacing and adjusting the carbons has also to be considered.

Cost of arc lamps.

Choice of arc lamps.

Great care is necessary in the selection of an arc lamp, and equally so in the choice of carbons, for, even if the lamp be a good one, it may flicker and vary unpleasantly if inferior or unsuitable carbons be used in it. A continuous current, or a rectified alternating current, is generally deemed more suitable for an arc lamp than an alternating current, but there are advantages and drawbacks in each. In a continuous-current lamp the positive carbon is placed in the upper part of the lamp, and has to be made nearly double the sectional area or double the length of the negative carbon, because it burns away approximately twice as fast. The top of the negative or lower carbon forms into a point, while the end of the positive carbon forms a hollow or a "crater," from which the bulk of the light is thrown down and diffused with little obstruction from the lower carbon. Moreover, the positive carbon is provided with a soft core which serves to keep the arc burning in the centre; the negative carbon is solid. For these reasons continuous-current lamps taking as little as 5 amperes give satisfactory results; and this may be deemed the minimum size of arc lamps, though those taking only 3 amperes are occasionally made. In an arc lamp supplied from an alternating current, both carbons, as they burn away practically at the same rate, are made of the same size, and much of the light is choked between the two. From these and other causes, arc lamps so supplied do not afford a satisfactory light with less than from 10 to 15 amperes. When the lamps are used indoors the humming which is apt to accompany the burning of alternate-current lamps is an objection. Because of these disadvantages it is usual, when an alternating system is established, to either put down a separate continuous-current generator for any arc lighting that may be required, or to "rectify" the alternating current, and supply the rectified current through a separate main. Up to 1898 much had still to be

Consumption of carbons.

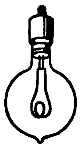
Humming of arc lamps.

Rectifiers.

learnt about rectifiers, which had not long been introduced, and as to the effects of the strongly pulsating current they produce. However, it may be said in favour of the alternating current for arc lamps, that while the pressure required by a continuous-current lamp is about 50 volts, and thus only two can be run in series in a 110-volt circuit, three alternating-current lamps may be run in series on 110 volts. Although the same expenditure of energy in the two lamps may give a larger volume of light than in the three lamps, the running of the three alternating-current lamps in series may in some special cases allow of a better distribution of the light. Again, if in the case of an alternating-current supply at 100 volts only one arc lamp be required, a "choking" coil may be run in series with the lamps, and this coil absorbs very little energy. In the case of the continuous-current lamp run from a 100-volt supply, the resistance which must be used to reduce the pressure absorbs as much energy as the lamp itself. Another advantage of the alternating current is that one arc lamp may, where necessary, be supplied from a small "transformer" giving current at the proper pressure.

Transformers.
See page 265.

So long as electric lighting could be effected only by the consumption of carbons, which need frequent renewals and attention, and an apparatus or arrangement at each lamp which could not be economically applied on a small scale, such a system could not be widely adapted to the numerous purposes for which single gas burners and oil lamps are used. If instead of consumable carbons, platinum wire conductors be rendered incandescent, a moderate light can be obtained without the necessity for moving parts or attention; but platinum is expensive, and affords no practical solution of this problem. The invention of the so-called Incandescent or Glow lamps by Swan and others supplied this want. In these lamps there is a continuous unbroken conductor, of so small a sectional area that the current passing through it meets a great resistance, and generates heat, the small conductor, which is of carbon, becoming white-hot and giving forth a brilliant light. The conductor in the lamp is usually made of a slight filament of carbonised cotton, cane, or other fibre, which, if it were subjected to the electric current while exposed to the air, would be burnt up in an instant. An essential principle of the incandescent lamp, therefore, is that in the glass globe where the incandescence occurs a vacuum is maintained, so that, as combustion is impossible without oxygen, the filament may remain unconsumed. So perfect


59.

Incandescent or glow lamps.

Incandescence in vacuo.

must this vacuum be that special pains are taken to produce it, and very elaborate mercury or Sprengel pumps have been devised for this purpose. The incandescent fibres, with fair treatment, last from 700 to 1500 hours before they perish, when the lamp becomes worthless and must be replaced. The above principle is common to all incandescent or glow lamps, but there have been numerous subsidiary inventions, mainly in regard to the shape, material, and mode of preparing the carbons, and the manner of attaching the lamps to the conductors.

Durability of glow lamps.

Incandescent lamps for ordinary purposes are made of from 5 to 32-candle-power, and where a more brilliant light is required, as for the lighting of shop fronts, high power lamps are made up to 500 candles. Instead of such powerful lamps, however, it is generally preferable to employ a group of 16 or 32-candle-power lamps instead of the large single lamps. Since the expiration of the patents of Edison and Swan the price per lamp has fallen from about 4*s.* to prices between 9*d.* and 1*s.* 6*d.* each for ordinary sizes, there being hardly any difference in price from 8 to 32-candle-power. The cheaper lamps may be used where there is much breakage.

Candle-power. *See page 242.*

Cost of glow lamps.

A certain voltage or pressure of current has been found most suitable for particular purposes. When lighting by incandescent lamps was first established, the candle-power specified was based on a current of 100 volts in the lamp filaments, a pressure which the lamp makers could meet. This pressure became stereotyped commercially, and was generally adopted. Hence the continual references by electricians and manufacturers to lamps of 100 and 110 volts and sometimes less. Subsequently, however, lamps have been made with filaments which will endure a higher pressure, and become incandescent with any desired voltage up to 230 volts. This voltage may be deemed about the maximum for incandescent lamps for domestic use, and while it extends the range within which lamps can be supplied direct from a low-tension system, it involves neither danger nor inconvenience. It must, of course, be borne in mind that as the above specified pressures are those in the lamp filaments, the pressure given out by the generator must be sufficient to allow for the power absorbed in the resistance of the leads or conductor-wires, due to their length or to insufficient capacity. The loss due to the resistance of the leads depends on their sectional area or capacity, and on the quality or conductivity of the copper. Taking as a basis for computation a current density equal to 1000 amperes per square inch

110-volt lamps.

230-volts.

Leakage and loss allowed for.

Loss from resistance.

Loss computed by distance.

Lighting area divided into zones.

Feeder conductors.

of sectional area, the loss would amount to 2·5 volts per 100 yards, or with 400 amperes per square inch (an economical rate for long distances) the drop would be 1 volt per 100 yards. The pressure given out by the generator must therefore be greater, to allow for such loss, than that required in the lamp filaments. If, for instance, the area to be lighted is within a radius of 800 yards from a generator giving a current of 200 volts, it might appear that the most economical results would be obtained by dividing the area into three zones, or belts, the lamps in the inner zone having filaments equal to a higher pressure than those in the outer zones. But it is found more convenient in practice to have all the lamps alike, and by means of feeder conductors radiating from the generator, and of sufficient capacity to transmit with little loss, to so connect them with the local distributing wires that there is at none of the lamps a greater drop in pressure than 4 volts. If it be much greater than this, the lamps in the outer zone would have a diminished brilliancy, or, conversely, the lamps near the generator would burn out.

Consumption of current.

Up to the year 1894 lamps consumed from about 3½ to 4 watts per candle-power, and lamps up to 32-candle-power, say for factory use or otherwise, where the price of electricity is low, can be obtained of this efficiency. For use in towns, where electricity is relatively dear, lamps can be obtained from 2½ to 3 watts per candle. This higher efficiency is obtained by running the filament at a higher voltage or pressure, as above referred to, thus reducing the life of the lamp. The extra outlay for renewing the high-efficiency lamps should be balanced by the saving in the cost of current, but this much depends on an unvarying voltage and on an unvarying quality of carbons.

Arc and glow lamps compared.

It will be noticed that, light for light, arc lamps are much more economical than incandescent lamps, but they are only suitable for lighting streets or open spaces, large workshops and buildings. For general purposes incandescent lamps are to be preferred. It has been proved by experience that 32 or 50-candle power lamps are best suited for lighting side streets or other open places too small or unimportant for arc lamps.

The supply of electric light to towns is usually carried out in one of two ways, i.e. either by

The Continuous-current system, coupled generally with the use of storage batteries or Accumulators, or by

The Alternating-current system.

Continuous current.

Storage batteries. *See page 268,* ACCUMULATORS.

A supply by continuous current is usually on the "low-tension system," and, broadly, consists of a network of mains, laid throughout the streets, which is supplied by "feeders" coupled direct to the dynamos. The dynamos generate current at a pressure of from 100 to 230 volts, and supply direct into the "feeders" or trunk mains, and may be connected in parallel with the storage batteries, which play a most important part in a well arranged low-tension system, and to which reference will be made further on. These accumulators serve several very useful purposes, viz. of maintaining a constant pressure during sudden changes of load, supplying the whole network during hours of light load when it is not economical to run the steam plant, and also being ready at any moment to assist to meet a heavy load in cases of emergency, when perhaps only a small portion of the generating plant is under steam.

See page 262.

Long distance transmission. *See page 504.*

The use of 200-volt incandescent lamps widens the field for what may still be classed as a low-tension system of lighting. To transmit the same energy the same distance with the same loss due to resistance, the size of the mains can, with the higher voltage, be reduced to one-half the previous section, or, with the same *percentage* of loss, they can be reduced to one-quarter the original size. Or, to state the case in a different way, either four times the lighting can be done in the same distance, or the same amount of lighting may be done at four times the distance. And, although the cost of insulation increases with the pressure, the difference in this respect between 100 volts and 200 volts, or between 200 and 400, is so slight that it may be disregarded.

Limits of low-tension supply.

Division into districts.

Town supply on the low-tension system at 100 or 110 volts can be carried out economically to within about one-third of a mile radius of the generating station, and with 230-volt lamps to two-thirds of a mile, but beyond these distances the mains have to be made large, or the percentage of loss becomes so great as to impose a heavy burden on the undertaking. To meet this difficulty in large towns two or more stations with mains interconnected have been established, but this is only possible where the demand is considerable. In London different districts have been assigned to separate companies, and where the area served from one station is limited, the low-tension system is in such a case generally used. But in some of the metropolitan districts the high-tension system is used, and in some both methods, and this diversity is likely to prove inconvenient in the event of any future amalgamation.

Alternating system. *See page* 257.

The want of some means by which the electric current could be economically conveyed long distances has led to the development of the second of the two methods just mentioned, viz. the "Alternating," sometimes also designated as the "High-Tension" system. This latter definition is not strictly correct, as the continuous current is also sometimes conveyed at a tension as high as 1000 volts. As, however, the continuous current has in the majority of cases been distributed and applied at a low voltage, while the alternating current has been used up to and even beyond 10,000 volts, the distinction of "high" and "low" has an accepted conventional meaning which is adopted here.

Transformers described.

It is the practice in ordinary high-tension stations to generate current at, say, 2000 volts, and this is reduced to the pressure suitable for the lamps in transformers, which are simply modifications of the well-known induction or Ruhmkorff coil. A core of laminated soft iron is wound with two sets of coils of insulated wire properly proportioned; in a reducing transformer the primary coils being of fine wire, and the secondary coils of stout wire. An alternating current, of say 2000 volts pressure, is passed through the primary coil and induces an alternating current, but of lower pressure and larger volume in the secondary coil, that is to say, more amperes at a lower voltage. Although by this system a very flexible method of transmission of electricity to a distance is attained, it has several drawbacks, for, while by adopting the high-tension system the mains may be reduced to any required section, and the losses due to fall of pressure are minimised, the losses in transformers in lighting a large area may be considerable during hours of light loads. This has led to the "banking" of transformers, wherever possible, instead of supplying each house from a separate transformer. The "banking" simply consists of forming groups of transformers in suitable positions, which feed into a low-tension network, as described under the direct-current system, the transformers being thrown into and out of circuit as the external load varies, either by automatic devices or by an attendant. By this means the transformers are for the most part used at full load, their most economical point.

Banking of transformers.

Again, although in the high-tension system a large saving of copper is effected in the feeding mains, much greater precautions as to the insulation of these mains have to be adopted than in the low-tension system, and these precautions involve a greater outlay. This, taken together with the cost of the transformers, and of the sub-stations in which they are placed, renders the high-tension system less suitable for lighting areas in near proximity to the generating station than the low-tension system. It is also to be noted in this regard that the rate of depreciation on mains subjected to high pressures and on the transformers, must be higher than in the case of low-tension mains, especially if they consist of bare copper strip in brick or concrete culverts. Unless the distances of the transformer stations from the generating station are sufficiently great, the cost of high-tension mains and transformers will together exceed the cost of heavy low-tension mains. As in the lighting of towns the underground mains form a considerable portion, often half, of the whole capital outlay, especially where, as in most high-tension systems, there are low-tension distributing mains, full weight must be given to these points.

Depreciation of plant. *See also pages* 473 *&* 770.

In the case of a continuous current, the electric energy can be stored up in accumulators for future use, while the high-tension system is at a disadvantage in this respect, as the alternating current cannot be put into secondary batteries. Therefore, during the hours of light load the steam or other motive power has to be kept continuously working, thus making the station charges heavier than would be the case if the demand could be supplied from accumulators. In some high-tension stations secondary batteries have been introduced, the plan being tried of charging them from special alternating-motor dynamos. The latter have not, however, proved satisfactory.

Day use of plant.

If the variation in the demand could be reduced by finding direct employment for the plant at times when little or no lighting was required, the high-tension system could be worked to greater advantage. For this reason, the need for some employment during the day, which arises in almost all undertakings for the sale of electric light, is strongest in the case of high-tension systems, and as the current can, when transformed, be used for power and heating, it is offered to manufacturers and others at a rate much below its equivalent in lighting power. Of course this necessity does not apply with such force in cases where electricity is generated by cheap water power. At one of the principal railway depôts in London, where a large electric lighting plant has been established, the power is utilised in the daytime for working deep-well pumps a mile distant.

Water power. *See page* 506.

Ferranti system at Deptford.

One of the boldest attempts which up till 1897 has been made in the application of high tension for lighting purposes is that by the electrician Ferranti, who generates a current at 10,000 volts at Deptford, where ample room and cheap fuel are obtainable, and which is seven miles from the lighting area in London. The cables are laid underground, and convey current to several transformer stations, where it is reduced to a pressure of 2000 volts, and conveyed to banks of transformers at various points, where it is again reduced to 100 volts. The same principle has been adopted on a still larger scale for conveying energy from Niagara to Buffalo, a distance of about 26 miles.

Power from Niagara.

Combined system.

An ideal system for a town thickly populated in the neighbourhood of the station, but stretching far away with a sparse population in the outlying districts, is a combination of the low-tension and high-tension systems. This method, which may be classed as a third system of distribution, lying between the two methods just described, is a continuous-current transformer system. In this the supply near the generating station is carried out on the low-tension system; but the supply to the outlying districts is performed through the aid of continuous-current transformers, which are supplied with current at pressures up to 1000 volts, and give out current at the lower pressure required. The continuous-current transformer is an ordinary motor, in which the armature is wound with two sets of coils, one set wound with fine wire (termed the primary) and one with large wire (termed the secondary), each winding being provided with a separate commutator and brushes. As the continuous-current transformers are rotary machines, having brushes requiring attention, they are more expensive in first cost than the alternating-current transformers, but they have been so perfected that they will work for many months without attention, and the system admits of the use of storage batteries for accumulating the supply during hours of light load.

Continuous-current transformers.

Methods of laying conductors.

There are several methods of laying electric light mains and wires, which may be briefly described. In regard to cost, overhead wires are much to be preferred, especially in scattered districts, where if buried wires are insisted upon by the local authorities the cost may be so great as to forbid the undertaking. Bare wires supported on insulators are, however, not to be recommended near houses where they convey a continuous current at a pressure exceeding 500 volts, or an alternating current above 300 volts, as anything beyond these pressures involves danger to life in case of accidental contact. There is no reason, however, why bare wires or conductors should not be used for conveying current at almost any pressure when they pass through private property, or through a sparsely peopled district, pro-

Bare conductors.

vided they are properly fixed, on poles raising them a safe distance above the ground, and due care exercised to prevent leakage. In most large towns overhead wires are prohibited by the local authorities, and cables efficiently covered with insulating compound, and which therefore are costly, are laid underground in pipes or conduits of stoneware, iron, and other material. As a cheaper plan "armoured" cables are laid direct in the ground without conduits. In either case junction-boxes are provided at intervals, where the house supply conductors are connected to the cables.

Underground cables.

Low-pressure conductors.

With a low-tension supply the mains are often simply strips of copper laid in concrete or brick culverts, supported at intervals on glass or porcelain insulators, and slightly strained so as to hang clear of the walls and bottom of the culvert. This method has met with considerable success, the first cost as well as the expense of maintenance and repairs being much smaller than with cables, and the facility with which new strips, or strips of larger capacity, are laid as the undertaking grows is found very advantageous.

The need for storage.

Storage batteries described.

See also page 266.

See page 492.

See page 254.

In the development of Electric Lighting the needs for some means of electric storage, so as not to depend upon connection with a continually-working generator, soon became apparent, for by this means the generating dynamos need not be constantly at work; and, moreover, the motive force, instead of being sufficient for the maximum call, as when all the lamps are alight, need only be enough for the average daily consumption. In fact, the storage batteries serve the same purpose as do hydraulic accumulators for serving numerous cranes, and in many cases an engine working for half a day can generate enough electricity for seven nights' lighting. There are certain substances, such as lead, which if subjected to the action of an electric current, when immersed in a suitable fluid, change their chemical condition, the electricity being employed in effecting the chemical change. The substance thus treated may, when arranged in plates in a suitable box or chamber of non-conducting material, be made to give out this stored-up energy somewhat in the same way as a galvanic battery does; and as the storage battery when exhausted can be replenished by again connecting it with a generator, there is not the great expense which attends the original production of electricity in a primary battery. There are numerous methods of applying the above principle, and invention has been successfully directed to overcome difficulties in the loss during the conversion of the current, in the

Leakage avoided.

Irregular speeds utilised.

leakage of electricity, and in the premature or irregular disintegration of the chemical material. Lead, in the metallic or oxide forms, is the material most commonly employed; while leakage is avoided by using boxes lined with sheet lead, or even, where only small cells are required, by casting the boxes in one piece from molten glass, so avoiding all seams or joints. Glass boxes are, however, liable to fracture from frost. Storage batteries or accumulators are obviously useful in providing against the sudden cessation of light from the accidental stoppage of a motor or generator. Even where no storage is necessary electric lighting is, in the case of a motor liable to variation of speed and unsteadiness, rendered more equable when the current is passed through a storage battery as a regulator. Thus motors running at irregular speeds may be utilised, if the maximum speed is provided for—and after passing through accumulators the electric current may be applied at a constant pressure. For instance, if the only motor available is one used also for other purposes and is irregular in speed, or, as another instance, where in the lighting of railway trains, power has been supplied to the dynamo from one of the running axles, the variation so produced in the dynamo would be quite unsuitable if the currents were applied directly to the lamps.

Portable accumulators.
See also TRAMCARS, *page* 315.

Weight and cost.

By means of portable storage batteries or accumulators electric lighting can be carried on for a time without a generator. For conveyance to a distance, the storage batteries are arranged in boxes of moderate size and weight, and if the accumulators could be rendered lighter and cheaper their use would be greatly extended. Under the most favourable circumstances they weigh from 100 lbs. to 130 lbs. per horse-power hour. In order to provide for five hours' illumination by 100 16-candle incandescent lamps, storage batteries weighing nearly 4 tons would be required. Besides the loss of energy in the transmutation, there are also the hire and deterioration of batteries having an original cost of about £3 per lamp. Such batteries are conveniently used for the temporary lighting of buildings, for lighting railway carriages, and small portable storage batteries are useful as safety lamps for mines, and for a variety of other purposes.

Electric Lighting Act of 1882.

Powers granted.

Restrictions.

In 1882 the Electric Lighting Act was passed, which regulated in Great Britain the terms on which local authorities, or joint-stock companies established for profit could, under the powers of Provisional Orders, undertake public electric lighting. In this Act the right to open up the streets and lay electric conductors is granted, subject to certain limitations in the use of overhead wires,

Permanent monopolies forbidden. *See page* 28.

Option of purchase.

See TRAMWAYS, *page* 293.

Act of 1888 extending term of lease.

and stringent regulations for the protection of telegraph wires. Most of these regulations applied equally to local authorities who seek powers and to private companies, but with a view of safeguarding the community against such permanent monopolies as already existed in regard to gas and water supply, it was enacted that the local authority should, in every case, have the right at the end of 21 years, to buy up the undertaking at the then value of the plant, and without any addition in respect of compulsory purchase or goodwill. These terms proved too onerous, and, as it was found that capitalists would not take the risks of such enterprises without the potential or speculative profit which a longer term affords, an amending Act was passed in 1888 extending to 42 years, the time when the option of purchase should become operative. The two Acts are read and construed together as one Act, and may be cited together as the Electric Lighting Acts of 1882 and 1888.

Terms by private agreement.

Purchase by local authority.

But other terms of pre-emption may be made by mutual agreement between the parties concerned, and embodied in a Provisional Order. Where a municipality is unable or unwilling to spend public money on a new undertaking involving risk, but desires to have the opportunity of acquiring it when the risk is past, it is not unusual to stipulate that the undertaking may be acquired after 21 years at a moderate premium, or at any time in exchange for so much of the Corporation Stock as will provide in interest an income equal to 5 per cent. on the capital of the Electric Lighting Company that has been properly expended. Leeds and Sheffield were so acquired in 1898.

Board of Trade Regulations. *See page* 2.

Under the powers of the Acts of 1882–88, the Board of Trade established certain regulations—

(*a*) For ensuring the safety of the public.

(*b*) For ensuring a proper and sufficient supply of electrical energy.

"Pressure" defined.

In these regulations the expression "pressure" means the difference of electrical potential between any two conductors through which a supply of energy is given, or between any part of either conductor and the earth; and—

High pressure.

(*a*) Where the conditions of the supply are such that the pressure may at any time exceed 500 volts if continuous, or 250 volts if alternating, but cannot exceed 3000 volts, whether continuous or alternating, the supply shall be deemed a *High-pressure* supply.

Extra high pressure.

(*b*) Where the conditions of the supply are such that the pressure may on either system exceed 3000 volts, the supply shall be deemed an *Extra high-pressure* supply.

Pressure of supply to consumers.

1. The *pressure of a Supply* delivered to any consumer shall not exceed 250 volts at any pair of terminals, except with the express approval of the Board of Trade given for special purposes.

Pressure of supply to transformers.

2. The pressure of a supply delivered to a *Transforming* station or to transforming apparatus on a consumer's premises may exceed 250 volts, but shall not exceed the limits of high pressure.

Limitations of extra high pressure.

3. An extra high-pressure supply shall not be given except to distributing stations or other special premises, and with the written *consent* of the Board of Trade, and subject to such regulations and conditions as the Board may prescribe.

Maximum current in conductors.

4. The maximum *Working current* in any conductor shall not be sufficient to raise the temperature of the conductor or any part thereof to such an extent as to materially alter the physical condition or specific resistance of the insulating covering, if any, or in any case to raise such temperature to a greater extent that 30° Fahr. The cross sectional area and conductivity at joints must be sufficient to avoid local heating, and the joints must be protected against corrosion.

Minimum size of conductors.

5. The sectional area of the *Conductor* in any electric line laid or erected in any street after the date of these regulations shall not be less than the area of a circle of one-tenth of an inch diameter, and, where the conductor is formed of a strand of wires, each separate wire shall be at least as large as No. 20 standard wire gauge.

Insulating material.

6. All material used for *Insulating* electric lines or apparatus shall be of the best quality, and thoroughly durable and efficient, having regard to the conditions of its use. Suitable provision shall be made for the protection of the insulating material against injury or removal. If the protection so provided be wholly or partly metallic, it shall be efficiently connected with earth.

Insulation test.

7. Every main shall be *Tested* for insulation after having been placed in position and before it is used for the purposes of supply, the testing pressure being at least 200 volts, and the constructors shall duly record the results of the tests of each main, or section of a main.

Maintenance of insulation.

8. The insulation of every complete circuit used for the supply of energy, including all machinery, apparatus, and devices forming part of, or in connection with, such circuit, shall be so maintained that the *Leakage* current shall not under any conditions exceed one-thousandth part of the maximum supply current; and suitable means shall be provided for the immediate indication and localisation of leakage. Every leakage shall be remedied without delay.

Leakage.

High-pressure conductors to be covered.

9. Every high-pressure conductor laid after the date of these regulations shall be continuously covered with insulating material to a *Thickness* of not less than one-tenth part of an inch; and in cases where the extreme difference of potential in the circuit exceeds 2000 volts, the thickness of insulating material shall not be less in inches or parts of an inch than the number obtained by dividing the number expressing the volts by 20,000.

Limit of power in high-pressure line.

13. A high-pressure electric line shall not be used for the transmission of more than 300,000 watts, or in the case of an aerial line 50,000 watts, except with the consent in writing of the Board of Trade, and efficient means shall be provided to prevent this limit being at any time exceeded.

Intervals between supports.

16. Every aerial line shall be attached to *Supports* at intervals not exceeding 200 feet where the direction of the line is straight, or 150 feet where the direction is curved or where the line makes a horizontal angle at the point of support.

Height and distance from buildings, &c.

19. An aerial line shall not in any part thereof be at a less height from the ground than 20 feet, or where it crosses a street 35 feet, or within 5 feet measured horizontally or 7 feet measured vertically from any building or erection other than a support for the line, except where brought into a building for the purpose of supply.

Angle of crossing streets.

21. Where an aerial line crosses a street, the *Angle* between the line and the direction of the street at the place of crossing shall not be less than 60 degrees, and the spans shall be as short as possible.

Suspending wires.

23. Every high-pressure aerial line shall be *efficiently Suspended* by means of insulating ligaments to suspending wires, so that the weight of the line does not produce any sensible stress in the direction of its length. All suspending wires, if of iron or steel, shall be galvanised.

Discharge of pressure in case of fire.

24. In the case of any high-pressure aerial line exceeding one half mile in total length, means shall be provided whereby the pressure may be *Discharged* from any portion of the line erected over or alongside of any building or buildings without loss of time in case of fire or other emergency.

Receptacles for electric lines.

27. All conduits, pipes, casings, and street boxes used as receptacles for electric lines shall be constructed of *Durable material*, and where laid under carriageways shall be of ample strength to prevent damage from heavy traffic; and reasonable means shall be taken to prevent accumulation of gas in such receptacles.

Crossing pipes.

28. Where any electric line crosses, or is in proximity to, any

metallic substance, special precautions shall be taken against the possibility of any *electrical Discharge* to the metallic substance from the line or from any metal conduit pipe or casing enclosing the line.

Electric continuity of metal conduits.

29. All metal conduits, pipes or casings containing any electric line shall be efficiently *connected with earth*; and shall be so jointed and connected across all street boxes and other openings as to make good electrical connection throughout their whole length.

Precautions against charging of short pipe, &c.

30. Where isolated lengths of metal conduit, pipe, or casing are used for the protection of any electric line at road crossings or similar positions, *special Precautions* shall be taken to prevent the possibility of any electrical charging thereof.

Precautions for bare conductors.

31. Where the conductors of electric lines placed in any conduit are not *Continuously covered* with insulating material they shall be secured in position, and no unfixed uninsulated material of a conducting nature shall be contained in the conduit. No such conductor shall be at a higher potential than 300 volts.

Access of water.

Adequate precautions shall also be taken to ensure that no accumulation of water shall take place in any part of the conduit, and to prevent any dangerous access of *Moisture* to the conductors or the insulators.

In the case of any such electric lines laid in conduits after the date of these regulations, the insulators shall be so disposed that they can be readily inspected.

High-pressure lines laid above ground.

32. Every portion of any high-pressure electric line placed above the surface of the ground, or in any subway not in the sole occupation of the electric lighting company, shall be *completely Enclosed* either in a tube of highly-insulating material embedded in brickwork, masonry, or cement concrete, or in strong metal casing efficiently connected with earth.

Proximity to other electric lines or to the ground.

33. Where any high-pressure electric line is laid beneath the surface of the ground, efficient means shall be taken to render it impossible that the surface of the ground or any neighbouring electric line or conductor shall become *Charged by leakage* from the high-pressure electric line.

Street boxes.

34. In addition to the provisions contained in Regulation 27 as to the construction of receptacles for electric lines, the following regulations shall be observed with respect to the construction of street boxes:—

Box covers.

(*a*) The covers of all *Street boxes* shall be so secured that they cannot be opened except by means of a special appliance.

(*b*) The *Covers* of all street boxes containing high-pressure apparatus other than cables shall be connected to strips of metal laid immediately underneath the adjacent roadway, and efficient means shall be taken to render it impossible that the covers or other exposed parts of these boxes, or any adjacent material forming the surface of the street, shall become electrically charged, whether by reason of leakage, defect, or otherwise.

Leakage.

Influx of water.

(*c*) Where street boxes are used as transformer chambers, reasonable means shall be taken to prevent as far as possible any influx of *Water*, either from the adjacent soil or by means of pipes; and in the case of any such street box exceeding one cubic yard in capacity, ample provision shall be made, by ventilation or otherwise, for the immediate escape of any gas which may by accident have obtained access to the box, and for the prevention of danger from sparking.

(*d*) All street boxes shall be regularly inspected for the presence of *Gas*, and if any influx or accumulation is discovered, immediate notice shall be given to the authority or company whose gas mains are laid in the neighbourhood of the street box.

Apparatus on consumer's premises.

39. All electric lines and apparatus placed on a consumer's premises shall be highly insulated and thoroughly *Protected* against injury to the insulation or access of moisture, and any metal forming part of the electric circuit shall not, unless efficiently connected with earth, be exposed so that it can be touched. All electric lines shall be so fixed and protected as to prevent the possibility of electrical discharge to any adjacent metallic substance.

Apparatus to be enclosed in metal, &c.

40. Where the general supply of energy is a high-pressure supply, and transforming apparatus is installed on a consumer's premises, the whole of the high-pressure service lines, conductors, and apparatus, including the transforming apparatus itself, so far as they are on the consumer's premises, shall be *completely Enclosed* in solid walls, or in strong metal casing efficiently connected with earth and securely fastened throughout.

Arc lamps to be guarded.

44. All *arc Lamps* shall be so guarded as to prevent pieces of ignited carbon or broken glass falling from them, and shall not be used in situations where there is any danger of the presence of explosive dust or gas.

Height from ground.

45. Arc lamps used in any street for public lighting shall be so fixed as not to be in any part at a less *Height* than 10 feet from the ground.

Cut-off switch.

46. Arc lamps used in any street for private lighting shall be

fixed so as not to be in any part at a less *Height* than 8 feet from the ground, and shall be so screened as to prevent risk of contact with persons. A cut-off switch, fixed in a suitable locked receptacle, shall be provided for every high-pressure arc lamp, and such switch shall be of such pattern and construction as will provide:—

(*a*) That the lamp can by its means be entirely disconnected from the supply circuit;

(*b*) That the switch itself can be safely operated in the dark without special precautions; and

(*c*) That there shall be no danger of any injurious electrical arcing, sparking, or heating being caused by the operation of the switch.

Penalties.

The foregoing rules are all liable to modifications or additions from time to time, and penalties are prescribed for their infraction.

Fire insurance rules.

But besides these Board of Trade regulations, there are also those of the Fire Insurance Offices, who, in order to ensure safety against fire, have made rules as to the strength of current as well as to the insulation of conductors. Copies of these regulations—which, however, apply only to short conductors, as in the wiring of houses, hotels, factories and theatres—are furnished to insurers, and conformity to them is verified by qualified surveyors before a policy of assurance is granted. A density current of 1000 amperes per square inch of conductor is permitted.

The Institution of Electrical Engineers in Great Britain has also issued rules which may conveniently be used in specifications as a basis for contracts. It is to be noted that as the inspection of local fittings and apparatus by corporations and companies who supply electric energy, and of the Fire Insurance Companies, are only in their own interests and for the purpose of insuring the public safety, they do not guarantee to private parties that the work is done well throughout.

Electric lighting and Gas compared.

In comparing the Cost and Advantages of Electric Lighting with those of Gas or other illuminants, a variety of circumstances have to be considered which vary in almost every case.

The introduction of the electric light was retarded by the fact that gas lighting was already established, and the question could not be settled merely on a comparison of merits. Thus arose the apparent anomaly that new districts and towns having no gas-works, and as therefore affording unrestricted openings, were equipped with the electric light before more advanced towns and cities, where the

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pecuniary results appeared doubtful. But experience has now fully proved the advantages of electric lighting, the incidents of production, distribution and sale are known, so that calculations of cost and profit can be made with reasonable certainty.

Advantages of electric lighting.

It may be said that while in countries where oil and coal-gas are as cheap as in England electric lighting is generally dearer than other systems of illumination, the superiority of the electric light greatly exceeds the extra cost. Secondly, in regard to the quality of the light, electric lamps give out little heat, and are free from the bituminous deposits and the vapour which in gas lighting are deleterious to the atmosphere, as well as to pictures, books and domestic fittings. Further, it is generally more convenient to lay conductors than gas-pipes, and there is not the risk of fire and explosions which always more or less attend the use of gas. So much is electric lighting recognised as the system of the future, that even in towns where it is not yet established it is deemed expedient when new houses are built to "wire" them ready for the electric light instead of laying gas-pipes. The cost of such wiring is about 25*s*. per lamp.

Noxious vapours of gas avoided.

It is by some objected that the electric light, proceeding as it does from one point or line of light, does not diffuse itself as well as gas, and casts sharper shadows. This, however, may be to a great extent obviated by lightly frosting the bulbs of the lamps, a plan which, although it slightly reduces the light, tends to the more complete diffusion of the light. Where the heavy shadows cast by the arc lamp cannot be sufficiently reduced by enclosing the arc in a frosted or opalescent globe, inverted arc lamps may be employed. In an inverted lamp the mechanism is arranged below the carbons, and the positive or larger carbon is placed beneath the negative and a whitened reflector is placed beneath the arc. By this means all the light is thrown upwards on to the ceiling or roof, and the latter having been rendered as white as possible throws the light downwards and diffuses it uniformly. This method has been successfully applied to the lighting of workshops and mills.

Diffusion of light.

Inverted lamps.

Electric light and gas compared.

In any system of town supply or public lighting the area and population to be supplied also affect the comparative cost. The production of gas is proportionately much cheaper on a large than on a small scale, partly because the manufacture, storage and distribution are cheaper, but largely also because the sale of bye-products, which go far to determine the net cost of the gas, is much more profitable where the quantities are considerable. Thus in London and other large cities illuminating gas is sold with profit at prices much below those possible in small towns. In London gas sells for from 2*s.* to 3*s.* per thousand cubic feet, while in small towns prices range from 3*s.* to 7*s.* With electric lighting, on the contrary, a town or district of 20,000 inhabitants can, if not too widely spread, be supplied nearly as cheaply as in the largest city, because in the latter case numerous centres of generation and distribution would be necessary. Electric light companies generally charge prices graduated according to the amount consumed as recorded by an electric meter, the rate or price per unit becoming less as the amount consumed becomes larger.

See page 250.

Prices per unit.

In London the maximum price charged by the public lighting companies has been fixed at 8*d.* per unit, the rate which private users actually pay ranges (1898) from 6*d.* to 8*d.*; but for large consumers lower rates are allowed for day consumption, and some companies will supply at 3*d.* or even 2*d.* per unit. It is found that if electric lamps are methodically switched off when not in use the light is really little more expensive than gas, for it is not possible to economise with gas in the same manner. If the price per unit for the electric lighting be multiplied by 10 the result will give approximately the equivalent in gas per 1,000 feet. As an example, if the electric light be supplied at 3½*d.* per unit it equals in cost gas at 35*d.* per 1,000 feet, or if at 6*d.* per unit gas at 60*d.* per 1,000 feet. But this comparison does not take into account the saving by the purer light, namely, the reduced cost of house decoration where electric light is employed, as against the renovation of decorations injured by gas fumes, a saving which is often considerable; or the greater convenience in placing the light so that it can be fixed exactly where wanted.

Compared with gas.

In comparing the cost of electric lighting with that of gas, it must be remembered that everything connected with the production and use of electricity is being gradually improved and cheapened, while the older system of gas lighting has reached a more permanent stage of development. Undoubtedly the competition of electricity has stimulated improvements in gas lighting. The brilliant light afforded by incandescent gas burners is a notable example. The direction in which further economy appears likely, is in the utilisation of bye-products.

Gas improved by competition.

See page 251.

Street lighting.

For public lighting efficiency much depends on the skilful disposition of the lamps and diffusion of the light. While street gas pillars are generally 8 ft. high, placed from 150 ft. to 300 ft. apart, arc lamps 23 ft. high can be effectively disposed at intervals of 500 ft. (For narrow streets 32-candle incandescent lamps in lanterns may be sufficient.) In wide or important streets the pillars may be erected in the middle of the street, and where there is not room for this the lamps may be hung from conductors suspended across the street, as at Milan and elsewhere. The plan of having powerful lamps of 5,000 candle-power and upwards on lofty towers or framed standards a quarter of a mile or more apart has not proved successful, as so much of the light is wasted.

Lamps suspended across street.

Lighting factories and hotels.

When electricity is generated privately for lighting a factory or large hotel the cost will vary from 2*d.* to 5*d.* per unit, according to the size of the installation, the facilities for generating electricity, and the cost of fuel. In a factory it frequently happens that steam is generated on a large and economical scale for driving the machinery, and a dynamo can be driven either from the main engine or a small independent engine, and placed under the charge of the existing engineering staff. In this case the cost of generating may be brought as low as 1*d.* per unit. In the above rates are included the interest on capital, as also a provision for depreciation, repairs and renewals.

But although it may be economical to take power from existing boilers, it is seldom desirable to take power from an engine used for other purposes, unless its speed and working be regular and equable. This, however, becomes of less importance where storage batteries are used, as has been evidenced by the working of dynamos from the axles of railway trains, the electricity passing through storage batteries. On board steamships the comparison is favourable to the electric light, because the boilers afford ample power; the distances for transmission are small; it is practically impossible to make or store gas; and oil lamps, while giving a poor light, involve much trouble in cleaning and trimming, besides being dangerous.

Electric lighting of trains.

Of steamships.

Whatever the power used for working dynamos, whether it be that of a steam-engine, gas-engine, water-engine, or other prime-motor, it may be applied either directly, by prolonging the working shaft of such motors to form the shaft of the dynamo; or indirectly, by a belt or ropes from the drum of a detached motor. There are the advantages in the first method of obtaining a compact self-contained machine, and without the inconvenience and friction of belting. But ordinary steam engines with reciprocating pistons cannot safely be run at the high number of revolutions most advantageous for dynamos

Prime-motor and dynamo in one.

Belting from detached motor.

Speeds.

Steam turbines. *See also page* 586.

For search lights.

of usual diameter, and for this reason a suitable speed is obtained either by driving from a large pulley on the motor to a small one on the dynamo, or by applying engines of moderate speed (say 250 revolutions per minute) direct to alternators by making the armature part of the fly-wheel and so obtaining a sufficient periphery speed. The convenience of making an engine and dynamo self-contained has stimulated the designing and manufacture of high-speed engines, with pistons and cranks so arranged and balanced that they will run steadily at 500 revolutions per minute. Although the larger proportion of such engines are for moderate powers of from 5 to 50 horse-power, such engines are also used for electric lighting up to 500 horse-power, and find much favour both in Europe and the United States. This demand for high speed has encouraged also the revival of rotary engines, which have always been the aim of inventors. The best of these, the Parsons turbines, run successfully at the extraordinary speeds of from 3,000 to 10,000 revolutions per minute, and are conveniently applied where a large force has to be concentrated into a small space. They are used for instance in steamships, especially in torpedo boats, or as portable machines for taking on board, for search lights or other temporary purposes. As an example, a steam turbine with dynamo or alternator complete (except the boiler), giving out 200 electric-horse-power, weighs only 5 tons, and occupies only about 40 sq. ft. of space. Since their success for electric-lighting has been demonstrated they have been applied to various other purposes and to higher powers.

Loss by friction.

Net efficiency.

In reckoning the gross power necessary to produce a certain electric efficiency, the losses from friction and other sources in the motor and those in the dynamo should be kept separate. As is explained elsewhere, the effective power of a steam engine is only from 80 to 90 per cent. of the gross or indicated horse-power, according to the quality of the engine and care in running it. As in the dynamo also there are losses, only about 88 per cent. of the power given from the belt of the steam engine or other motor is converted into electrical power in the armature of the dynamos. The electrical efficiency, after deducting the power absorbed in heating and otherwise, is only about 94 per cent. of the gross electrical power; so that if an engine of 100 H.P. give an effective 80 H.P. to the pulley of the dynamo, the commercial net electric efficiency is only 94 per cent. of 80 H.P., or say 75 horse-power. Better results are obtainable, but it is prudent not to reckon on them in designing the plant, and in practice a still further margin should be assumed in calculating the gross motive power necessary.

Water power utilised.

Compared with steam or gas. *See page* 283.

Great saving in expense is often anticipated by the utilisation of natural sources of water power as a substitute for the fuel consumed by a steam-engine. The capital cost, however, is generally as great for the water power as for steam, and may be even greater if dams, conduits, storage reservoirs and other adjuncts have to be provided. This expenditure may, of course, be amply justified by the saving not only of fuel, but in the periodical replacement of boilers. In Great Britain the cost of coal in well managed electric lighting installations need not exceed ½*d.* per B.O.T. unit, and with large economical engines, or gas-engines, even ¼*d.* may be made to suffice. It is in localities where fuel is dear and water force not only abundant but constant, that water motors are advantageous; and especially also where the electric force can be utilised for tramways or other power purposes. Such conditions are often found in Switzerland for instance. Hydraulic power mains are not well adapted for giving economical rotary motion, but an interesting example of an intermediate transmutation of force on a small scale is afforded by the use of water at a pressure of 700 lbs., purchased from a power company at the current price of 2*s.* per 1,000 gallons, the water force being applied, by means of a Pelton Wheel, to the driving of a dynamo, and furnishing electric light on these conditions at about 8*d.* per B.O.T. unit.

Power from hydraulic mains. *See page* 493.

Gas motors. *See page* 602.

In factories where power is already established it can generally be arranged to work an electro dynamo also, or if there be no existing motor available a gas-engine or oil-engine will generally prove the best motor, and it may be reckoned that 25 cubic feet of gas will be consumed for each electric unit generated, or its equivalent of oil in an oil engine. Or, to state the case differently, 1·6 or, at most, 2 cubic feet of gas will afford power for one 16-candle lamp for one hour.

Arc lamps of 1,000 candle-power (taking 10 amperes) supplied from a central station at 6*d.* per unit, would cost about 4*d.* per hour, including the cost of carbons and trimming.

Estimates of cost.

In estimating the *Cost* of an electric lighting installation very full consideration must be given to the sufficiency and quality of the plant as well as to the general design. Competitive tenders are seldom based on similar detailed specifications, because each manufacturer or contractor has methods and patterns of his own which cannot be easily compared with those of others; and there is a wide scope within which, while nominally affording the same result, the machinery supplied may vary much in value. The capacity of dynamos is for similar machines running at the same speed in proportion to the weight, or perhaps a little greater. The capacity of the generators, their speed and the margin provided, the size, weight, or capacity of the conductors and their connections, as well as the materials and thoroughness of the insulation, are examples of such variance. A tender or estimate of cost should not only define clearly what it is intended to include, but if subsidiary work is necessary should indicate what is left to be done by others. The provision or adaptation of buildings, the expense of excavation, masonry, or carpenters' work may often with advantage be left to the purchasers, who may also transport the material and provide unskilled labour or other services. These points should be enumerated, for it is the total outlay that has to be considered in making comparisons. A tender for an electric lighting installation should include all patent rights, or in express terms define those which are excluded. In this regard it must be remembered that patents which have expired in the country where the contract is made may still be binding in the country where the apparatus is to be manufactured or installed.

Need careful definition.

Patents.

In Great Britain the modern tendency towards Municipal undertakings has led in many cities to establishing a public supply, and money is borrowed on the security of the rates at a low rate of interest. In such cases the lighting of the streets, as well as the sale of light for shops, factories and houses, is provided for.

Municipal undertakings. *See page* 8.

The considerable number of towns and districts which have adopted the electric light has rendered available much information as to cost and results, and as in Great Britain the Board of Trade, under whose rules all public companies are established, call for detailed annual returns, these allow of convenient comparison. But great discrimination is necessary in drawing conclusions from the results, and especially in regard to the relation which the current cost of working bears to the capital outlay. As in all engineering undertakings, undue cheapness in construction may involve great expense in repairs and renewals. But apart from the quality and sufficiency of the work, the relation between the two depends on the system adopted. As already stated, a low-tension system may cost more for the main conductors, and two or more generating stations may be required for supplying a certain area instead of the smaller mains and one central station of the high-tension system. But the cost of

Tabulated results.

Undue cheapness.

Earnings gradually increase

Expensive sites.

working of the low-tension plant may be so much smaller as to more than compensate for the interest on the higher capital. In estimating the revenue that may be expected from a given expenditure of capital, it will in most cases be obvious that the earning will only be gradually developed. Unless for supplying a specific area and a precise number of lamps, the generating plant and main conductors must be considerably in excess of immediate wants. If, however, the ultimate prospects be favourable, capitalists will generally be content with a very moderate return for the first few years, and it may even be wise to refrain from dividing any profits for a time. As, therefore, it is usual to provide for an increasing output, the capital expenditure should be measured rather by the capacity of the plant than by the actual sales effected or revenue obtainable. At any rate a fair analysis can seldom be made till the plant has been working two or three years. It is obvious, however, that the capital expenditure may vary within wide limits. In this regard the first question is that of the site of the generating station. It may be expedient to have this in a central place, which in a city may be costly. If the land be purchased the total capital outlay may be swelled considerably, though the interest on the purchase may be met by an equivalent saving in rent and by other advantages. But while there must be some capital outlay affording only a dormant or future profit, much expenditure may be postponed till the occasion for it is evident. Thus, while space may be provided for additional engines, boilers, and dynamos, the machinery itself need not be provided; conduits may be made large enough for additional conductors, but the great expense of the copper conductors may be postponed.

Capital per kilowatt.

High cost: how caused.

Cost per B. O. Trade unit. *See page 256.*

In Great Britain, up to the year 1895, the returns of the Electric Lighting Companies show that the total capital expenditure per kilowatt capacity varied within the very wide range of from £60 to £150. The higher rate is in many cases due to excessive preliminary expenses; but it has generally occurred also in those installations where preparations have been made for an increasing output. The sites for power houses, the buildings themselves, the opening up of streets and the laying of conduits have often, especially in large cities, to be much in advance of the immediate demand of consumers. The total cost of production and distribution, including management and depreciation, but exclusive of interest on capital, ranges from 2½*d.* to 6*d.* per Board of Trade unit, with exceptional cases outside these limits. But the experience gained shows that in the future with a well-arranged and well-managed plant the cost need not exceed 3*d.* per unit. As the statutory price obtainable in Great Britain ranges from 6*d.* to 8*d.* there is ample margin for reduction in the actual price charged by the companies. Out of the probable cost, that of coal for steam-engines depends on the skill in management and the current cost of coal. The consumption in well made steam-engines as applied to electric lighting in Great Britain ranges from 4 lbs. to 14 lbs. per electric unit generated, according to the constancy of the load, but as in the best modern gas-engines of 100 H.P. and upwards working with producer-gas, the consumption of coal is only from 1½ to 2½ lbs. per unit, it is with such engines that electric lighting is likely for the future to find its economical development.

Coal consumption.
See page 572.

See GAS ENGINES, *page* 602.

A portion of the earnings may be set apart for depreciation of plant and as a reserve or sinking fund, to balance the wasting value of a property held only for a term of years and for which payment will be made only for the value at the time of surrender. Some of the original outlay, such as legal and other preliminary expenses in obtaining statutory power, is obviously valueless as a permanent asset. This, if taken separately, may be entirely written off in the earlier years of working. Other expenditure, such as for land, and for opening up the streets and securing a right of way, may not need any depreciation, but taking all the reserve, sinking fund, and depreciation together, the best managed British companies set aside annually from two to three per cent. on the whole capital. It does not follow that the total capital as stated in the books becomes less, because new expenditure for extensions or remunerative improvements may balance or more than balance what is written off.

Term of years.
See page 270.

Sinking fund.
See pages 39 & 293.

Depreciation.
See page 770.

In elaborating a scheme of electric lighting, in Estimating the Cost, and calculating the probable profits, the following are the leading circumstances that have to be considered :—

Basis for a scheme and estimate.

1. The general *purpose* in view and the extent of area to be lighted. In installations of considerable extent, as, for instance, those for street lighting or for large areas, or numerous rooms, the general system of distribution must be settled before any details can be arranged. Electrical circuits can be arranged in many different ways, and financial success or failure depends to a large extent on the initial laying-out of a scheme, and on the suitability and sufficiency of the system of conductors. It having been determined whether the lighting is to be by one or other kind, by arc lamps or by glow lamps, or

The general purpose.

Number and power of lamps. by both, the number and power of the lamps must be settled. On the extent and kind of lighting, and the distances apart, will depend whether the whole will be best served from one central station, or whether the area is to be divided into several circuits or districts. Regularity or uncertainty in the number of the lamps to be in simultaneous operation is an important point. **Hours of lighting.** If all the lamps have to be lighted or extinguished at the same time, as, for instance, might occur in street lighting or the illumination of a public building, the system would be simpler and cheaper than in the case where the number of lights was continually changing, as must occur in the supply to numerous users or to the different rooms of a large hotel. If the light is wanted for factories or for any other special purpose, full particulars are necessary of the operations to be carried on and of the locating of the lights. It is obvious, therefore, that the electrical engineer must have a plan of the area or building, and either the position of each lamp shown upon the plan, or such a description of the purpose required as will enable him to arrange the lamps to suit it. **Area to be lighted.** In the case of rooms or any covered space, not only their shape and size, but their height are of consequence. The maximum and average number of hours per day when the lamps are likely to be used must also be made known.

Right of way. 2. The *right of way* for the electric conductors must be obtained or affirmed. In this regard municipal or other rules as to the pressure of current permitted, and safe insulation and protection of the main leads, will have to be considered. The introduction and rapid extension of electric lighting has in some foreign countries been rendered possible only by the lawless way in which overhead wires have been taken without leave. **Way leave.** Permission given to attach conductors to the houses, or to erect poles in the streets, to cross main avenues, or to lay conductors below the roads or footpaths, may in effect be the granting of a monopoly if similar privileges be withheld from others. The position and purpose of any existing conductors for electric lighting or power, or telegraphs or telephones, must be ascertained and considered, so far as they are in the way of, or likely to be affected by, the contiguity of the conductors in the proposed scheme. In some cities subways under the main streets afford convenient places for laying conductors, but in most cases the conductors have to be laid in troughs or pipes in shallow trenches excavated for the purpose, **Conduits.** conduits or covered troughs in great variety of form and manufacture, pottery, bitumen, concrete, and other non-conducting material being employed. In the case of overhead conductors peculiarities or extremes of climate and heavy rainfalls must be considered.

Climate. *See also page 74.*

3. In any scheme for public lighting the *sites* available for stations must be selected and the terms settled upon which boilers, steam-engines, or other motors will be permitted. If the lighting scheme is limited to one building, or to a small area, it is still necessary to ascertain that a suitable place is available for the motor and generator, and, if need be, for storage batteries.

Station sites.

4. Cost of the *rent*, *taxes*, water, and other charges, the class of fuel available and its price, or of gas, oil or pressure-water for motors, if it appears cheaper to obtain power in any of these ways, are important points for consideration.

Rent, rates, taxes, fuel, and gas.

5. If the scheme be one for selling the light to different users, the rates or prices obtainable will depend to a large extent on the prices paid for the *existing means* of lighting—electricity, gas, oil, or others—and on the quality of such existing lighting. As a new system is seldom established till a certain amount of custom is assured, particulars of the minimum and probable maximum demand must be gathered, especially with regard to the number of hours per annum during which the light will be required, as well as the obligations likely to be enforced by the municipal or other public bodies. If the scheme depend upon a monopoly, permission, or other concession, granted by the local authority, the length of the term and the conditions of pre-emption or surrender at the end of the term are matters of great importance.

Prices obtainable.

See Chaps. II., III.

6. If there is a demand for *motive power*, which may be supplied from the electric light conductor, the system chosen should allow of its proper distribution.

Sale as power.

7. If the scheme is one in a *foreign country*, or at a distance from those who are devising it or providing the design or capital, such local information as to cost of material, labour and transport must be furnished as has already been described for other engineering undertakings.

Local cost of labour, &c. *See page 74.*

The foregoing remarks have been directed to lighting schemes of a permanent nature. For *temporary installations* where the lighting is for a limited time, as during the construction of buildings or bridges, or for the lighting during the season of an exhibition or public garden, then various modifications will be expedient, especially in the manner of laying and supporting the conductors and attaching the lamps.

Temporary installations.

Patent rights.

Amongst the difficulties which have unavoidably attended the introduction of an entirely new method of lighting, have been those arising from the conflicting claims of inventors and patentees. The choice of methods and apparatus has been in many cases hindered by the disputes and litigation arising out of the monopolies of patentees and those to whom patents have been assigned. Although, doubtless, continued improvements will for many years to come be the subject of new patents and monopolies, yet as the original patents which cover the main principles and forms of apparatus have lapsed or are lapsing by effluxion of time, there will be the greater freedom for the choice of method in each case as it arises.

Each case on its own merits.

In the description given in this chapter no attempt has been made to decide the choice between different systems, and too much stress cannot be laid upon the necessity for referring each individual case to properly qualified, experienced and independent electrical engineers, as upon the correct choice of system in the first case depends the after success of the undertaking.

[*See also* CONCESSIONS : ELECTRIC TRAMWAYS : ELECTRIC TRANSMISSIONS : GAS LIGHTING : THE ESTABLISHMENT OF FACTORIES.]

CHAPTER XIII.

TOWN TRAMWAYS.

TRAMWAYS differ from Railways in that they are laid along the common highway whose levels or contour they follow. Tramway rails must be flush with the road or otherwise subordinated to the general traffic, while railways have raised rails and more regular gradients. The occasional exceptions where raised rails are allowed on highways are dealt with elsewhere. Iron tramways for conveying passengers in towns were in operation in the United States twelve or fifteen years earlier than in Europe. This arose from a variety of causes. The want of convenient conveyances for passengers was much greater in American cities than in London, for the service of omnibuses and cabs was less efficient, while the inconvenience, so loudly proclaimed then and since by the opponents of tramways everywhere, that the iron rails would spoil the roads and obstruct the traffic, had not much weight in American cities, where the streets were generally badly paved.

See page 77.

Town tramways in America.

Earlier than in Europe.

Tramways profitable.

Tramways opened out a new field for engineering enterprise, and, if established on proper conditions, they afford a safe and remunerative return for capital. If judged by the price that investors will pay for shares producing a certain amount of interest, tramway undertakings do not in England differ much from railways, and it may

Compared with railways.

Tramways less uncertain.

Growth of traffic.

Limited term of tramway leases. *See page 291.*

Permanently high profits forbidden.

therefore be assumed that the advantages and disadvantages of the two undertakings nearly balance each other. When first commenced, the works of a tramway are much sooner remunerative than are those of a railway, and there is not so much room for uncertainty in the amount of expenditure either for works or for purchase of property. Moreover, an increasing traffic does not augment so largely the proportionate expenditure for maintenance as in railways, because the wear upon the permanent-way and street paving is determined not only by the number of tram-cars which pass, but largely also by ordinary vehicles; and the greater the car traffic the greater will be the share of advantage which the tramway proprietors will obtain for an expenditure for maintenance which must in any case be incurred. On the other hand, railway shares have a speculative value arising from the expectation of increased profits in the distant future, as is clearly evidenced by the prices paid for shares in non-dividend-paying lines. These potential profits are limited in the case of tramways to the term of the concession or lease (in English towns seldom exceeding 21 years), as it is not usual to grant perpetual rights as with railways; and when a tramway undertaking pays dividends high enough to give a more than par value to the shares, the public, as represented by the municipal authorities, will, when the time for renewing the lease arrives, claim to participate in the profits either by a reduction in the tariff of fares or by an increased rent for the use of the road, or will exercise their power of purchasing the undertaking. If, however, the line has paid no more than a nominal rate of dividend, the proprietors will be left to work it as before. Such conditions give a one-sided aspect to the transaction as between the town and tramway proprietors, which doubtless does much to limit the value of the investment in the estimation of capitalists. Although very large dividends have been earned on some foreign tramways, and the shares have attained a proportionately high price, these cases have arisen where favourable terms had been granted by the authorities at a time when the value of such enterprises was unknown.

Advantages offered by tramways.

The advantages which a tramway offers to the public are—more comfortable travelling, a more frequent and regular service, and lower fares, than omnibuses afford; and as undoubtedly the tramway does to some extent interfere with other traffic, the real justification for such lines is that the accommodation they afford to the majority of

Goods traffic unfeasible.

Distribution and delivery.

Exceptional cases.

See pages 76 & 513.

Municipal night service.

the inhabitants far outweighs the inconvenience to the minority. While, however, these benefits justify the establishment of tramways for passenger traffic, there has been much misapprehension in regard to their use for conveying goods; engineers, as well as promoters, having in many cases failed to appreciate the very different conditions which such service, to be successful, demands. In many of the authorising Acts of Parliament for tramways in Great Britain, rates of toll for parcels and merchandise have been inserted, but in some of these cases the right to carry heavy goods or minerals is made subject to the permission of the local authorities. The profitable conveyance of merchandise and parcels for short distances in towns, generally involves the distribution and delivery of the packages at particular places, and it is evident that tram-cars, with flanged wheels which must keep to one route and may not obstruct the streets by other than momentary stoppages, cannot compete with ordinary distributing carts; and although in exceptional cases, such as the conveying of goods from a railway station to one particular warehouse or market, or from a harbour to a custom-house, or from a manufactory to a port, tramway delivery might even, for short distances, be performed with advantage if the merchandise be in sufficient and regular quantities, no miscellaneous carriers' duty could be undertaken. When, however, the distance exceeds four or five miles, the cheaper haulage which a tramway allows—especially if economy be further obtained by the use of mechanical haulage—might justify such an undertaking, and repay a second handling of the goods and the cost of final distribution from the terminus. The circumstances by which any such project should be determined are, however, so different to those connected with a town tramway for passengers, that a scheme for combining the two services, involving, as it might do, the risk of failure in both, should be propounded only after careful consideration. The use of a passenger line for mail-cars or supplementary work at night, such as the conveying of road-mending material, or town refuse, are independent questions which concern the municipal authorities rather than the proprietors of the tramway.

Tramway concessions.

The conditions upon which tramway concessions are granted, though they vary in different countries, generally do so only in detail, as there are certain primary points—principally the letting by lease and the obligation in regard to the street paving—which are common to all cases. In Great Britain an Act of Parliament is necessary for the construction of tramways, this power being obtained

Provisional Orders. *See page 9.*

generally by Provisional Orders of the Board of Trade. The great majority of tramways have been constructed and owned by joint-stock companies, and, under the Standing Orders, the promoters have first to prove that they make their application with the consent and approval of the local authority. As easier terms in this respect are allowed by the Light Railways Act of 1896, it is likely to be availed of for urban tramways. Up to the year 1890 it was only rarely that the municipal authorities either constructed or owned a line, for the growing tendency towards the undertaking of public works by the authorities was up to that time limited to such purposes as water-supply, gas or electric lighting and drainage works. Tramways, however, as interfering with the streets and street paving, have been since included in the category of undertakings to which municipal funds may be properly applied, and Corporation loans authorised by the Legislature. In some cases, e.g. at Sheffield, Manchester, and Bristol, the tramway has been made by the Corporation and leased to a company at a yearly rental. In Glasgow the Corporation constructed the tramway and also maintained it, the company which first undertook the working paying to the Corporation interest on the actual capital expenditure, and an agreed sum annually for the renewals and repairs; though if this annual sum proved more than sufficient for the purpose in view, the balance was to be returned or credited to the company. But on the expiration of the lease the Corporation not only purchased the property, but have since worked it. In Leeds most of the tramways were constructed by private companies, whose interests have been acquired by the Corporation, with the intention, since carried out, of working the lines. Under the terms of English tramway concessions hitherto granted, it is probable that many more of the lines constructed by private companies will hereafter become the property of the public by purchase; and in the case either of construction or purchase by public authorities, the necessary money may be raised by loan in the manner prescribed for local public works generally. But while in England municipal bodies have been allowed to construct or acquire tramways, they were at first forbidden to work the lines unless they could show that they could not be let on equitable terms, Parliament in this matter restraining the modern tendency of town authorities to commercial enterprise. But this restriction was relaxed in 1896 for some special cases, and is hardly likely to be again enforced, the Standing Orders having been altered so as to enable local authorities to obtain power to work their own lines. By whomsoever the tram-

See page 76.

Municipal tramways.

Examples.

Purchase of tramways.

See LOANS, *pages* 118, 210.

Supervision by Board of Trade.

way may be made, the Board of Trade exercises, as in the case of railways, considerable power of supervision both in regard to the mode of construction and the working of the line. In France a similar power is exercised by the Minister of Public Works, who has every detail submitted to him for approval.

British tramways.

Concessions for tramways are generally given for terms of years. In Great Britain the usual stipulation in the authorising or confirmatory Acts of Parliament is, that at the expiration of a certain period (generally 21 years) the local authorities shall have the option of purchasing the undertaking from the proprietors, on the terms stated in the Act. After 21 years of working it is to be presumed that the pecuniary success or failure of the enterprise will be settled. If successful, the authorities will exercise their option and purchase the tramway, though perhaps leasing it again to a company on conditions equivalent to an increased rental. In many cases there will probably be no actual purchase or transfer, but the terms of maintenance, tariffs of tolls, and other conditions will be revised or altered in a way more or less favourable than before to the public or the proprietors, according as the working of the tramway has been profitable or otherwise in the past.

French tramways.

In France the term allowed to the earlier companies was 30 years; in other cases terms even up to 60 years were granted, but by the more recent concessions a term of 40 years seems to have become established in France as a standard. In most of the French concessions the tramway becomes at the end of the term the absolute property of the public authorities without any payment whatever, the rolling-stock being purchasable at a valuation; such conditions (which in France are those usual, though with a longer term, for railways) requiring on the part of the proprietors the establishment of a sinking fund before any dividend can properly be paid.

German tramways.

In Germany, periods of from 10 to 30 years have been allowed (25 and 30 years being the most usual periods), and the earlier concessions were granted on conditions which would allow of a renewal on similar terms, if experience showed nothing detrimental to the public interests. But after tramways had become well established, the tendency was towards a shortening of the term and to the imposition of more onerous conditions on the concessionaire.

Italy.

In Italy the concessions for town tramways have been generally for periods of from 30 to 40 years, the tramway and its equipment becoming the property of the town at the end of the term, the conditions in this, as in several other minor matters, resembling those usual in France.

United States.

In the United States the earlier charters (or franchises) were obtained for little or no payment, and with but slight obligations in regard to paving. In some cities the profits became so large as to raise the shares to many times their nominal value. More recently, onerous conditions of paving and road maintenance were included in the charters, which generally declare also the conditions under which the proprietors of the tramway may be called upon to remove it, but without specifying any particular time.

Terms of purchase.

In the year 1893 the first occasion arose in England for the municipal purchase of tramways, and as the interpretation of the lease formed a precedent which has since been followed, the circumstances may be quoted. In the 44th section of the London Street Tramways Act, 1870, it was provided that the local authorities might, on the expiration of 21 years from the construction of the tramway, "require such promoters to sell to them their undertaking, or so much of the same as is within such district," upon terms of paying them their value (exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale or other consideration whatsoever) of the tramway, and all lands, buildings, works, materials, and plant of the promoters suitable to and used by them for the purpose of their undertaking within such district, such value to be, in case of difference, determined by an engineer or other fit person nominated as referee on the application of either party." In the year 1891 the London County Council resolved to exercise its right to purchase 4½ miles, or nearly a third of the company's system, which had been 21 years in existence, and notice was given to the company accordingly. It was endeavoured to arrange a price, but the shareholders in the company concerned were unwilling to accept a value based on the worn condition of the plant, or to forego the value of the goodwill, and it was argued that though past and future profits were to be disregarded, present profits were to be taken into account. This view not being accepted, a referee or umpire was appointed to adjudicate. As the first occasion on which such a principle of valuation was to be applied, considerable interest was taken in the case by all those who had embarked capital in similar undertakings.

Goodwill not allowed.

Purchase of London lines.

Price, how awarded.

The umpire appointed under the Act issued his award in March 1893, as follows:—"I determine and award that the sum of £64,540 is the value of the purchased tramways and the works thereof (other than such works as are comprised in the annexed agreement), exclusive of any allowance for past or future profits of the undertaking or any compensation for compulsory purchase, or other consideration whatever, except the consideration of the value to the Tramways Company or to the County Council, measured by what it would cost either the Tramways Company or the County Council to establish the purchased tramways if such tramways do not now exist, but taking into account a proper deduction in respect of depreciation. And, accordingly, I determine and award that the value of the purchased tramways, and of all lands, buildings, works, materials, and plant of the tramways company, suitable to and used by them for the purpose of the undertaking of the purchased tramways, as such purchased tramways, lands, buildings, works, materials, and plant are defined by the annexed agreement, is the sum of £64,540, together with the further sum or sums payable under the annexed agreement, and such sum or sums together form the 'then value' of the premises within the meaning of the 44th Section of 'The London Street Tramways Act, 1870.' And I award and direct that the County Council do pay to the Tramways Company the costs incurred by the Tramway Company of, and incidental to, negotiating, preparing, and executing the annexed agreement."

Cost price allowed.

Less depreciation.

The agreement referred to in the above award provides *inter alia* for the Council acquiring certain depôts for sums in addition to that awarded, and also provides for the Council purchasing cars, harness, horses, &c., at a price to be determined "by some person practically acquainted with the value thereof."

Purchase of loose plant.

It was after this decision that the tramways in Glasgow and Leeds previously alluded to were acquired, and on similar terms. Accepting the award as a correct interpretation of the statutes under which most town tramways have been authorised, it will be seen that capitalists in constructing tramways must reckon on a revenue sufficient not only to pay a satisfactory annual interest, but also to meet the reduction in the value of the plant due to wear and tear. With the capital value so written down and a corresponding reserve established, the price paid when the property is transferred will be sufficient to restore the whole of the capital. It will be noted also that the arbitrator measured his value by "what it would cost either the Tramway Company or the County Council to establish the purchased tramways," and there is nothing to show that he has not taken

Reserve for depreciation.

into account and allowed something for the legal, parliamentary and other preliminary expenses incurred in establishing the tramway, but which are not represented by tangible assets.

Expediency of tramways, how determined.

There are certain main points by which the expediency of introducing tramways into a town may be determined, by which also the choice of system may be guided, and the probabilities of profit measured. They are :—

1. The Population of the town and the situation of the suburbs.
2. The Width and degree of regularity of the streets. *See page 295.*
3. The Gradients. *See page 300.*
4. The kind of Rail-track and road-paving. *See page 302.*
5. The Cars. *See page 308.*
6. The Hauling of the cars by Horses or Mechanical traction. *See page 312.*
7. The Cost of construction. *See page 323.*
8. The Revenue. *See page 324.*
9. Minor obligations, privileges, and bye-laws.

Although all the above points are subjects of discussion when tramways are proposed, points 2, 4, and 6 are those which mainly concern the town authorities, and on which controversy principally arises. For the rail-track and road-paving chiefly determine the cost of a tramway, and all the points together the expenses and profits of working. These several subjects may be elucidated as follows :—

Population.

Busy traffic most remunerative.

Suburban traffic.

1. *The Population of the town and the situation of the suburbs.*—As the profits depend upon the proportion which the gross earnings bear both to the capital and to the working expenses, it is obvious that a large busy population will be the most remunerative. A line upon which four cars per hour pass will have cost nearly as much as if twenty cars per hour were running, and the working expenses for the smaller number are in proportion heavier; therefore the capital and the current outlay obtain the best return—as expressed by the mileage earnings—from a population that affords a constant succession of passengers along the whole route. Suburban or "omnibus" traffic of this sort is more profitable than that on a line which connects two towns, between which there is little intermediary traffic; for in the latter the mileage will probably be long in proportion to the number of persons carried. A frequent service of cars, only possible with a considerable population, gives greater revenue proportionately than a service with intervals of more than five minutes,

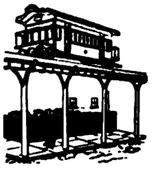
because would-be passengers for short distances will walk sooner than wait for a car. Hence a frequent service of small light cars is often more remunerative than a less frequent service of large cars. On the other hand, in a town compactly built, with few or unimportant suburbs, or with only short distances to traverse, there is but little inducement to ride, and if there be much ordinary traffic in the streets, a tramway would be inconvenient and unprofitable. There are few towns in England having less than 40,000 inhabitants (except at places of pleasure resort) where tramways would be remunerative ; but with regard to the likelihood of profit much depends upon the area covered, and upon the habits and occupations of the people. In some foreign cities with an enervating climate which indisposes people to walk, a very large proportion of the people will pay to ride.

Tramways seldom profitable in small towns.

Climate.

Width of Streets.

2. *The Width and regularity of the streets.*—The establishment of tramways is often opposed on the plea that the streets will be obstructed by the cars, which cannot leave the track. The crowded condition of the streets in the centre of a city forbids the construction of tramways in those very cases where additional means of conveyance would be specially useful; and in such places as London, where through-traffic is much impeded, the evil will probably so increase as sooner or later to demand a remedy. The system adopted in New York and Liverpool of overhead, or, as they are called, "elevated" railroads, is by some advocated as a suitable means of relieving crowded streets, but they cannot be compared with a road tramway, for they are above the street level, are not so accessible as tram-cars in the streets, and the stoppages are only at fixed stations. Such lines take the place of the London underground railroads, and owing to their convenience in this respect they are likely to be much adopted in the future. In London, tramways are not allowed in the central area of about one square mile known as the "city." But although in the centre of a crowded city tramways cannot with propriety be constructed, experience has shown that in any but a few extreme cases, tram-cars assist, rather than obstruct, free circulation, because they keep the traffic in line. Straight wide streets are obviously the best for tramways, as not only is there then no fear of their causing obstruction, but there is the less necessity for ordinary vehicles passing upon the tramway track. In horse tramways the greatest inconvenience is felt at the terminus, where the cars must necessarily be detained while the horses are



60.

Overhead Railways.

Traffic kept in line.

Cars turned at terminus.

changed from one end of the car to the other, though to reduce the time so occupied, the plan is sometimes adopted of having turn-tables or of pivoting the car upon its under-frame, so that the horses, without being detached, turn the car round while the wheels remain stationary. But to prevent any stoppages of the roadway, the line may be made to end in a side street, or a continuous or circular tramway without any terminus may be constructed, or—especially in the case of long steam-cars—the turning may be effected on a triangle track.

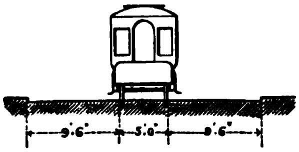
Width of streets.

Official rules.

Width of cars.

Single lines.

In England, according to the usual regulations, tramways are only permitted in those streets where a space of at least 9 ft. 6 in. is left between the foot-path and the nearest rail. Assuming that the extreme width outside the rails for a standard-gauge line is 5 ft., then a width of 24 ft. between the foot-paths (61) is necessary for a single line, and for a double line having a mid-space of 4 ft. between the up and down tracks (62), a width of 33 ft. is necessary. The maximum width of a tram-car is 7 ft., and as the car thus projects 12 in. outside the rail, a clear width of 8 ft. 6 in. is left for vehicles passing or standing between the rail-track and the foot-path. Opposition to tramways has even been based upon the alleged necessity of allowing carts to back up to the foot-path when unloading, which of course would involve a space greater than that necessary for carts standing parallel to the road. The width of ordinary vehicles varies from 6 ft. to 7 ft.; and 8 ft. may be accepted as a maximum. In France the usual regulations allow single-line tramways only in streets 7·50 *metres* (24 ft. 7 in.) wide, and double line in streets 9·80 *metres* (32 ft. 2 in.). Tramways have, however, in various countries been constructed in streets narrower than those just described, and in England and France also exceptions are occasionally allowed to the standard conditions.



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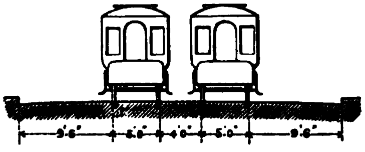


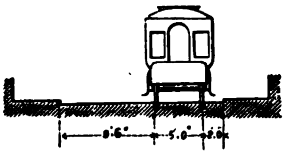
62.

Narrow streets.

When a street is narrow for a short distance only, and where the roadway cannot conveniently be altered to the desired width, permission is sometimes given for the rails to be laid for a limited distance near to the footway; the granting of such an indulgence

Clearance space allowed.

generally depending on the wishes and influence of the householders or traders in that portion of the route which will be affected. As, however, in any case it is necessary that sufficient space for ordinary vehicles should be left on one side or the other, the tramway is, in streets less than 22 ft. wide, laid at one side (63), instead of in the middle of the street, where each car as it passed would sweep the whole street. Thus, sometimes, where houses along the route are few, and where the inhabitants or authorities consent, a single-line tramway may be laid for a considerable distance with only a space of 18 in. or 24 in. between the outer rail and the footpath. Thus again, where there is a double track, the two lines may be laid (64) on one side of the street. But in the case of such double lines it is necessary that there shall be frequent crossing points, so that the cars on the side next the footpath may cross over to the other line when the track is obstructed by vehicles standing by the footpath. In some cases where the streets are in places too narrow for a double line, and the traffic too much for a single line, it has been found convenient to apply the interlacing system. This is a cheaper construction than a multiplicity of passing places with numerous points and crossings, and less costly to maintain. As the space between the rail and foot-path is required mainly to allow ordinary vehicles to halt in front of a house or shop, there is not the same need for the side space along suburban roads where there are no houses or shops; and in such cases, especially if the establishment of a tramway is popular, the stringency of the ordinary rules may be relaxed.



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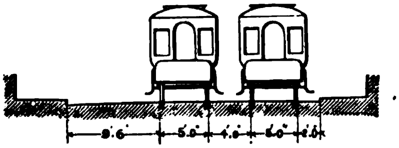


64.

Interlacing system.

Loop system.

Whatever the kind of passing-places, delay and inconvenience arise in the working of a single track, and to avoid these, it is a usual plan, where streets are too narrow for any doubling of the track, but where parallel streets are available, to work on what is known as the loop system, the cars running in a perpetual circle, one street being used for the up line and the other for the down line, the direction of the cars being sometimes indicated on the lamp-posts. Unless, however, the two tracks are near together, and easily reached by cross streets, there is some loss of local traffic, as a line available only in one direction is apt to be neglected in favour of ordinary omnibuses, which are not so restricted. A loop, therefore, should be made as short as possible, the double line being resumed wherever the width of street allows it.

Rail gauge.
See also page 58.
Narrow gauge.
One-horse cars.
Irish gauge.

Various gauges of width between the rails have been tried, but although a few tramways have been constructed as narrow as one metre, 3 ft. 6 in. and 4 ft., the standard gauge of 4 ft. 8½ in., or some close approximation to it, has been generally adopted where there is ample width of roadway; from 4 ft. 6 in. to 5 ft. 3 in. being limits which include the great majority of town tramways in Europe and America. The standard railway gauge seems to have been adopted originally for street tramways to enable railway trucks to run on them, a clause to that effect having been inserted in some of the earlier Acts, so that the tramways might be utilised for intercommunication between different stations and railway lines. But this power seems never to have been used, and the narrower gauges are often deemed more suitable for the sharp curves met with in street tramways. In Birmingham the 3 ft. 6 in. gauge which was applied to the earlier lines has been adopted for all the subsequent lines. Two horses cannot run abreast between rails much closer than the standard gauge without treading on the rails, which would cause them to slip. But where one-horse cars are used, or mechanical traction, a gauge as narrow as one metre may be adopted if circumstances demand it. The narrow gauge allows an easier transit over curves; and in towns where the streets are narrow and sharp curves numerous, narrow-gauge lines may occasionally be adopted with advantage. As the obstruction to ordinary traffic depends not on the width between the rails, but on the width of car, it is the body of the car that must be reduced if any reduction in the area of road occupied is to be effected; but as the width of the cars is determined by the space necessary for passengers, it is undesirable to have cars narrower than 6 ft. 6 in. if it can be avoided. A gauge wider than 4 ft. 8½ in., though unnecessary for the cars, is more convenient if ordinary vehicles are to use the track; and in some of the tramways of the United States, where the track is intended for general use, a wide rail with a projecting shoulder is laid with 5 ft. 2 in. gauge inside the projection. In Ireland the Irish railway standard gauge of 5 ft. 3 in. was adopted for the tramways, under the idea of using them for railway trucks between the principal stations. This wide gauge was inconvenient for sharp curves, and to meet the difficulty the wheels on one side of the cars were made to run loose on the axles. The unsuitability of the wide gauge for sharp curves was demonstrated in 1895 at Dalkey, near Dublin, on the then new electric tramway. In Liverpool, on an ordinary railway line laid through the docks for goods traffic (the rails being level with the ground), omnibuses with unflanged wheels ran regularly till the omnibuses were superseded by the elevated railway; and the plan has even been tried on the Continent, of changing the wheels of the cars during each journey, when they arrive at or leave the rail-track.

Width of mid space.

Economy in width is obtained sometimes by reducing the space (*entre-voie*) between the up and down lines; but the saving so obtainable is very small. As each car projects from 10 in. to 14 in. beyond the rail a space of at least 3 ft. is necessary; and 4 ft. or 4 ft. 6 in. is given where possible; but the space is often reduced to 3 ft. 6 in., or even (for a few yards at special points) to 3 ft. While, however, a minimum clearance of 18 in. between passing cars is generally deemed necessary, a clearance of only 9 in. has been permitted where the form of car ensures the safety of the passengers entering and leaving the cars. Thus in Moscow, one-horse cars are used which have sliding doors on one side, the other side and both ends being closed. As there are projecting steps only where the doors occur, the car has a lobsided appearance. In a double line the space is generally determined by the length of the car and the nature of the curves, as the platform ends of a long car project considerably beyond the rails in rounding a curve.

See page 311.

Wheels without flanges.

When the sanction of the road authorities to a tramway is withheld because of the narrowness of the streets, which might be blocked by tram-cars unable to move from the track, the difficulty may be partially met by constructing the wheels of the tram-car without flanges, so that they run only upon the rail and not in the groove of the rail; the car being kept upon the track by a small guiding-wheel in front of the ordinary wheels, running in a groove, either on one or both sides of the car. When it is desired to leave the track, the driver can do so by raising the guiding-wheel from the rail-groove by a lever, the car having then all the liberty of an ordinary omnibus. A similar arrangement to this was tried on the first tramway running to Peel Park, Manchester. This plan, which has also been in operation on a portion of the tramway lines in Hamburg and

Guiding wheels.

Copenhagen, resembles in some degree the system at Liverpool, but has the obvious disadvantage that the weight of the loaded car must be determined by what the horses can draw in a short effort when off the track, although, of course, there remains in favour of the horses for the greater distance the ease of traction on the rails.

Curves.

As a tramway must follow the existing lines of streets, curves are unavoidable, especially in old towns; the more difficult cases, however, being those where the track passes from one street to another at right angles; but wherever the space allows it the radius of the curve should be as great as possible. But though in curved streets, or at passing-places, an easy radius is generally obtainable, there are cases where the track is so continued from one street to another that sharp curves are unavoidable. At such places a radius of 80 ft. is frequent, and occasionally 50 ft., or even in some rare cases, 20 ft. is all that can be obtained. Although tram-cars can, as already stated, be pulled round sharp curves, they undergo a severe strain, and the track at such places needs frequent repairs. The difficulty arises from two distinct causes, one, that as the wheel on the outer rail has to travel a longer distance than the wheel on the inner rail, to which it is united by the same axle, one wheel has therefore to slip on the rail, so increasing the friction and abrasion; the second cause is, that the two axles of the car are parallel, while the curve demands that they should radiate from the centre of the curve, and owing to the non-flexibility of the cars in this respect there is great friction between the wheels and the rails. It has been attempted to meet the first difficulty by allowing one wheel upon each axle to run loose, so that it can revolve independently of the other, but wheels so arranged need careful attention or they would soon get out of order. Another plan is to cut the axle in the middle, so that each with its wheel revolves independently, though with the same axial line as the other. It has been attempted to meet the difficulty by pivoting the car on short "bogie" trucks, as is done on railways, and this is generally on large cars drawn by a locomotive; but on the great majority of tramways the passage of cars round sharp curves is mainly facilitated by the short wheel base which is generally adopted, and in towns with narrow streets and where sharp curves are unavoidable, the adoption of a narrow guage of 3 ft. 6 in., as in Birmingham, or the gauge of one metre would be advantageous.

Minimum radius.
See also page 63.

Inconveniences of sharp curves.

How remedied.

Gradients.

3. *The Gradients.*—A hilly city is not favourable for tramways

worked by horses, steep inclines being even more unfavourable to tram-cars than to ordinary vehicles. The superiority which metallic rails have over an ordinary road lies in the level smoothness of the surface, the absence of small inequalities, and in the consequent ease of traction. On a level route the advantage of a rail track over the best highway in regard to the haulage power required to keep the cars, when once started, in motion, is about as 6 to 1, and if compared with a rough or badly-kept road, is even as great as 10 to 1. But these advantages, while afforded by a railroad where the rails are raised, are not obtainable on a town line with grooved rails which hold grit and mud. There is then little difference in favour of the tram line as compared with a smooth wood or asphalte road. Still, because of the generally more easy traction the tram-cars can be, and generally are, much more heavily loaded than omnibuses drawn by the same number of horses. While, however, the skill of the engineer is thus effectual in reducing friction, the increment of resistance due to gravity on an ascending gradient cannot be reduced, and as the loaded tram-car weighs more than the omnibus, the resistance is increased in a greater proportion. For instance, on a gradient of 2 in 100, the dead weight of the loaded car has to be lifted vertically two feet for each 100 feet traversed; or assuming the weight of the loaded car to be 8000 lbs., and therefore this number of foot-pounds to be raised, an extra force of 160 foot-pounds has to be exerted for each foot of forward motion. And as the tractive force necessary to draw such a car on the level is only from 70 to 140 lbs., according to the condition of the rails, it will be seen that a gradient of only 2 per cent. will double or treble the force necessary to haul the car.

Superiority of rail track on level.

Resistance due to gravity cannot be reduced.

See page 63.

On long lines of tramway, with generally level roads, occasional moderate gradients may be overcome without extra horses, because horses are capable of great effort for short periods; but where the ascents are steep or continuous, extra horses are necessary. Long level tracks with a few sharp ascents are less distressing to the horses than long stretches of even slight incline. The reduction in speed, the strain and wear and tear on the horses, and the consequent increase of working expenses which frequent or steep gradients involve, tell heavily against the profits of a tramway. In London the gradients range from 1 in 25 to 1 in 3000, there being a few long stretches of from 500 to 900 yards with gradients of 1 in 60, and a few short steep ascents of 1 in 25 and 1 in 30. It is in the substitu-

Extra horses necessary on hills.

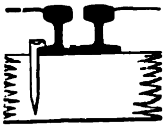
Mechanical haulage.

See pages 313–17.

tion of steam or other mechanical haulage for horse traction that the solution of difficulties arising from steep gradients lies. Cars with powerful motors can ascend gradients of 1 in 15 without difficulty, while cable cars can surmount any gradient however steep.

Tramway rails.

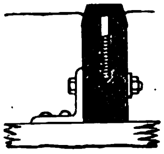
4. *The kind of Rail-track and Road-paving.*—Tramway rails have to satisfy two principal conditions, which to some extent are in conflict. The rail must, by a groove, a shoulder, or otherwise, accommodate a flanged wheel, and it must obstruct as little as possible the ordinary traffic of the road. It is obvious that a raised rail, such as is used upon a railway, would interfere with ordinary vehicles, and wherever tramways have been introduced, conformity to rules having regard to this is demanded by the municipal authorities, the conditions being stricter in some cases than in others.



65.

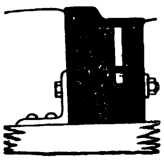
Guard rails.

On country roads, where there is space for the tramway without trenching upon the track of ordinary vehicles, a raised rail may be permissible, as in the case of the Douglas electric tramway in the Isle of Man, the Dublin and Blessington, the Portrush and Giant's Causeway, and other lines. But these may be classed among "light railways," referred to in another chapter. But if such a tramway is continued into a town, the rail must be made level with the road surface; and to do this effectually a second, or guard rail (65), must be placed, as is done on the level crossings of railways. Such a method (which has been used in Berlin and on other German tramways) is not generally adopted, and in a climate like that of England the groove between the rails is liable to be obstructed by dirt.



66.

In the earlier tramways of the United States an almost plain bar of iron was used as a rail, but the flanges of the wheels soon wore an irregular groove or rut between the rail and the road paving. The crescent rail, as this is called, although still used on some of the less important lines in America, has been generally superseded by rails of an entirely different kind. The grooved rail (not however, till 1890, of the forms used in England) is adopted on some of the tramways in America, but the rails in general use there, and known as the American step rail, while varying on different lines in regard to form, are not grooved, but have in common a flat surface and a projecting shoulder, features in which they differ radically from the grooved rails used in Great Britain. Figs. 67 and 68 show the earlier types of these rails, which were sufficient for light horse-cars, but with heavier cars and mechanical haulage much stronger rails have become necesssary, of



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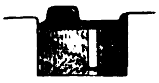

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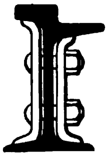


69.

which Fig. 69 is an example. These rails range from 4 in. to 8 in. deep, and weigh from 35 lbs. to 70 lbs. per yard. They may be placed on timber sleepers or concrete, and in some cases the granite paving setts are arranged so as to project and form a groove, minimising the obstruction to ordinary traffic. The American rails are undoubtedly the best for the tramway proprietors (unless they are responsible for damage to other vehicles), for the shoulder gives a sufficient side bearing for the flanged wheel, with less friction than that caused by the grooved rail; the surface is wide enough to allow latitude for irregularities in the gauge either of the track or the car-wheel, and the rail is easily kept clean, a circumstance of great importance in towns specially liable to snow and dirt. It is obvious, however, that the projecting shoulder is a great obstruction to ordinary traffic, and in American cities, when such rails are used, it is difficult for ordinary vehicles to cross the track except at right angles to it. But in the principal American cities the standard of excellence in regard to a level road surface is likely to attain that usual in Europe. Various kinds of rail have been devised to meet the conflicting conditions aboved described—the side bearing for the flange, absence of friction, easy cleaning, and at the same time a flush surface for the ordinary traffic. But such attempts have not been successful, and in Great Britain and on most of the Continental tramways a projecting shoulder on the rail is not allowed, no condition being more jealously enforced in new concessions than that of the flush rail, which presents the minimum obstruction to ordinary vehicles. In Great Britain this found expression in the animated and often acrimonious discussions in Parliament and in the local governing bodies, which preceded the authorisation of tramways in 1865–72.

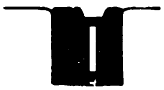
See also page 305.

Flush rails obligatory in Great Britain.

Grooved rails flush with road.

The grooved rails, laid flush with the road as on most European tramways, present, in theory, no obstruction whatever to the general traffic of the streets, for while the wheels of ordinary vehicles can run upon the surface of the rails, and, if the line be in good order, cross them without jolting, the groove is too narrow to allow of wheels slipping into it—a liability which would obviously render the track unsafe. The narrowness of the groove is, however, an inconvenience to the tramway company, as it is liable to be obstructed by dirt or grit, and requires constant attention to keep it clean.

The earlier forms of grooved rail were made with a flat base (70), and were held down to the sleepers by vertical spikes, this arrangement allowing the rail to be easily fixed or replaced without



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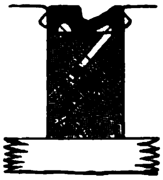
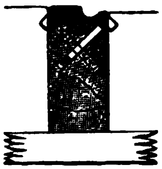


71.

Box-rails.



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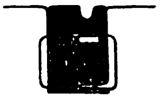


73.

disturbing the road or substructure; but it was found that such spikes cannot resist the strains caused by cross-traffic or by the natural tendency of the rail to curve upwards; that the spike-holes weakened the rail and admitted moisture to the timber, causing it to decay; and that some kind of side fastening is necessary. A remedy widely adopted to meet these defects was the box-rail (71, 72, 73), with holes only in the side flanges. These rails have been laid on many of the European tramways, and are still in use on many horse-car lines. But while a great variety of systems have been devised and numerous forms of rail patented, yet so long as rails have to be attached directly to longitudinal timbers there is great difficulty in maintaining a good track in cities where the traffic is severe, and especially where there is also great moisture.

The general adoption of street tramways in Europe having directed the attention of many engineers to the subject, led to further improvements in the permanent way, determined to a large extent by the local standards of street paving and by the nature of the ordinary carriage traffic. While, on a railway, the wearing of the rails depends upon the kinds of engines and carriages, and the frequency of the running, the endurance of a street tramway depends more upon the amount of ordinary wheeled traffic, and on the grit or mud allowed to accumulate on the principal roads.

Timber supports.

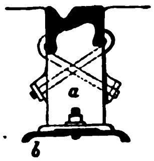
In European cities longitudinal timbers were in 1898 becoming obsolete, and this is for some reasons to be regretted, as the timber absorbs vibrations and the cars ran with less noise than on a metallic and concrete base. Timber is also less trying for steam engines, but as the slower motion renders an elastic road less necessary than on a railway, it is considered on the whole desirable to take advantage of the great durability of steel as compared with that of timber.

In cities with busy traffic the heavily laden drays and waggons subject the rails, not only to pressure and abrasion, but to side wrenches which tend to disturb the width of gauge, and cause grooves and ruts where the street paving joins the rails. An increase in the weight and strength of rails, and the use of metallic sleepers, have been the directions in which improvement has been sought.

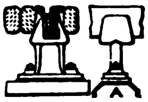
There has been a great variety of such systems, and the choice depends on the nature of the substratum or road foundation which is available. Where there is only a loose or sandy soil, or even where there is old macadam, sleepers of some kind which grasp a considerable

Pressed steel sleepers.
See also page 671.

area are necessary. Pressed steel in a trough form is then convenient. If laid longitudinally, the sleeper *b* (Fig. 74) can then either be continuous or laid at intervals as an elongated shallow pot sleeper with cast-iron chairs or stools *a* for receiving the rails. Another plan is to support the track on cross sleepers A (Fig. 75) with cast-iron chairs high enough to allow the stone paving setts to be well above the sleepers, the soil in the space between being well rammed. This method is sometimes adopted where the expense of a concrete base cannot be incurred, but in such cases the paving setts are sure to yield under heavy traffic and to give an uneven surface.



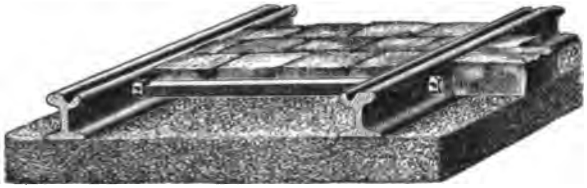
74.



75.

Concrete foundations.
See page 307.
See page 303.

A permanently solid roadway can only be constructed with a substratum of concrete which, while it affords the best base for ordinary street traffic, is also the best kind of support for the tram rails, which can then be laid without the interposition of any sleepers or chairs. In America, where after 1895 a solid road bed of concrete was coming into use in some of the American cities, beam rails (Fig. 69) with a projecting lip or shoulder were so laid. In England, where in all large cities concrete is used as a basis for any kind of paving, whether stone, wood, or asphalte, the beam rail was becoming universal after 1890 except for lines with light horse-cars. These rails (Fig. 76) have a base wide enough to transmit the load to the concrete, and, in fact, serve as sleeper and rail in one. They range in depth from 5 in. to 9 in., with flanges 3 in. to 6 in. wide, and weigh from 40 to 100 lbs. per lineal yard. They cost about 30*s.* per ton more than the price current for railway rails. The maintenance of gauge is assisted by tie-rods across the track, and by strong fishing-joints. Fig. 77 shows such an arrangement.



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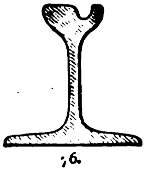


76.

Maintenance of rail joints.

The durability of the road bed depends largely on the effective maintenance of the rail joints. It is found that weak joints shake under the jarring of the cars and so loosen the concrete substratum and deprive the rails of their support. This evil is partly met by using

Electric-welding. *See page* 786.

Cast-welded joints.

Bonding. *See page* 321.

long and strong fish-plates. In some American cities the plan was tried, in 1894, of electric-welding the rail joints *in situ* so as to form one continuous rail. This, though intended as a substitute for bonding in electric tramways, would remedy the above evil, but the welding plant is costly and there is the expense and trouble of cutting the rails when they have to be replaced. Another plan has been tried in America of the "cast-welded" rail joint. A mould is formed round the joint *in situ*, and molten iron run into it from a portable furnace. The mode of traction goes far to determine the weight and strength of rail. For horse-cars, light rails will last a long time, while for locomotive traction or for any electric system, stronger rails are necessary because the cars are heavier. For most electric systems the rails must be bonded with copper to form effective conductors for the return current.

Maintenance of road.

Conditions in France.

In England.

In America.

See page 303.

From the commencement of tramway enterprise it has been the almost invariable condition in the concessions, or charters, that the proprietors of the tramway shall pave, and maintain in good order, not only the space between the rails (and where there is a double line the *entre-voie*, or inter-space), but a certain width beyond the outer rails also. Thus, in France, the outside strips of paving to be so laid and maintained by the concessionnaires are 0·450 *metres* (18 in.) wide on macadam (*empierrées*) roads, and 0·250 *metres* (10 in.) on paved roads. In England 18 inches was formerly specified; but the demands of the road authorities have become more exacting than in the case of the earlier tramways, and on some of the metropolitan lines the whole street (up to a width of 30 ft.) has to be paved by the tramway proprietors. In the large cities of the United States, although conditions as to paving and other matters are nominally imposed, the tramway companies have asserted and have been able to maintain a greater independence of the municipal authorities than is allowed in European cities, and the standard of quality in road paving has been a much lower one. In the principal American cities, however, these conditions have since 1894 been rapidly changing for the better.

Macadamised roads insufficient.

Where the roads chosen for tramway routes are only macadamised it would be cheaper for the tramway proprietors, if their own traffic were alone in view, to maintain the road material as they find it, or, at most, if the traction be by horses, to put a light paving in the horse-track. It is, however, impossible to keep the macadamised roads level with the rails, and even the plan of laying one row of granite

Granite paving.

Ruts formed.

See pages 302–5.

setts between the rail and the macadam has been found insufficient where there is much street traffic and variable weather, as in England. On the best made lines, therefore, it is customary to pave the entire surface which is under the charge of the tramway company with granite blocks or setts; other kinds of stone paving, or wood blocks or asphalte, being used in some localities. But, whatever be the material with which the road is paved, it is always liable to wear into a rut at its longitudinal junction with the rail; and the evenness of the road surface being thus disturbed, ordinary vehicles are jolted as they pass over the track, and this, though of little consequence in the case of carts and waggons, is a constant source of grievance to those who ride in carriages. The paving has to be frequently relaid or adjusted, or in some cases the granite re-worked *in situ*, the rut projections being cut away. Various alterations in the construction of the permanent-way have been tried to remedy these evils, but their success largely depends on the co-operation of the road authorities.

Divided authority.

Rent paid by maintenance.

The difficulties in connection with the street paving arise, to a large extent, from the division of authority over the road, and the hurried manner in which the tramways have frequently to be constructed. If the entire width of the street could be given up to the tramway engineers for a time sufficient to allow a solid concrete foundation to set properly, and if then the paving were laid uniformly from curb to curb across the street, the tramway being taken as a non-yielding standard level, the chances in favour of maintaining the road in good order would be much increased. Indeed, when a tramway is to be first laid, a convenient opportunity is afforded to the road authorities to construct a good road, or to change a macadamised to a paved road; and they might, with fairness, contribute a reasonable share of the expense. In so far as the tramway company bears the cost of paving a road which is to serve for general traffic, and of the total wear of which only a small proportion is due to the tram-cars, the saving to the road authorities may be considered as rent paid by the tramway company, and in any statement of cost and profit such expenditure may conveniently be kept distinct.

Saving to the public in road maintenance.

In the construction of a tramway, the road-paving forms one of the most important items of expense. In English cities granite setts (generally from Scotland, Guernsey, or Cornwall) are used for paving, and the exact cost of the material, in each case, depends on the distance from the quarries and the expense of carriage. The paving

Cost of road paving. of some of the most crowded streets of London is formed of granite setts as deep as 9 in., laid on 9 in. of concrete, but 7 in. granite on 6 in. of concrete is the general depth for roads along which tramways have been laid. The cost of picking up and conveying away the materials of a macadamised road is about 1*s.* to 1*s.* 6*d.* per superficial yard (according to the cost of cartage), and the expense of paving depends on the local cost of concrete and granite. Lime concrete laid in place costs, in English towns, from 8*s.* to 10*s.* **Concrete.** per cubic yard, and the thickness of 6 in., usual as a substratum to paving, may be valued at 1*s.* 6*d.* per superficial yard. Granite setts, 7 in. deep and 3 in. wide, cost in London from 33*s.* to 38*s.* per ton (including about 12*s.* per ton for carriage from the quarry), and one ton will, when laid in place, cover 3 square yards, the labour costing about 9*d.* per square yard. The total expense of altering a macadam road to one paved with granite averages about 15*s.* per square yard. Including the first cost of paving, and the expenses of renewals and repairs, it has been found (after taking credit for the **Cost of maintenance.** selling-price of worn setts) that the cost of granite paving in London taken over a long term of years (excluding a few very exceptional cases), ranges from 10*d.* to 1*s.* 6*d.* per square yard per annum, according to the severity of the traffic.

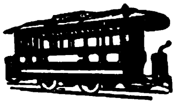
It will be seen from the foregoing figures that the paving with **Granite on concrete.** granite on concrete of a track 8 ft. wide, as suitable for a single tramway, including 18 in. of paving on each side, will, according to the English standards of price, cost about £3500 per mile; and of a track 17 ft. wide, for a double tramway, about £7500 per mile. In many city streets already paved, it is not necessary to lay new concrete and new granite over the whole route, and the cost is so much the less.

Tramcars. 5. *The Cars.*—Various kinds and sizes of cars are used on tramways, and the choice is, in each case, principally determined by the climate, the amount of traffic, and the gradients. Although there are great differences in the length of cars, the width is generally from 6 to **One-horse cars.** 7 ft. One-horse cars vary from 8 ft. to 15 ft. in length, seating from 10 to 22 persons. An open one-horse car weighs, when empty, from 20 cwt. upwards, and costs from £70 to £100. A closed car weighs from 24 cwt. to 30 cwt., and costs from £120 to £150. One-horse cars are most suitable for level lines, where there is a small or constantly changing traffic; the tramway in such cases being much more likely to be popular and profitable if small cars run frequently than if large cars run at longer intervals. As one-horse cars weigh more, in proportion to the accommodation they afford, than two-horse cars, either the passengers must be limited in number or the strain upon the horses be increased, and therefore it is very important to keep the weight as low as possible. Where the wages of two men would bear heavily on the earnings of the smaller one-horse cars, the passenger fares may be collected by the driver; and what is known as the "fare box" system has been successfully adopted in America and in some European towns to meet such cases. As the passengers pass into the car they deposit the fare in a box by the side of the driver, he being furnished with packets of small money for those who need change; but no change is given for coins dropped into the box.

"Fare-box" system.

If the numbers in all countries be reckoned, the great majority of cars are constructed for inside passengers only. Such cars, if with two horses, generally vary in length from 10 ft. to 16 ft., and have seats for from 14 to 24 passengers, although, in the absence of effective bye-laws, a much larger number will crowd on or into the car. The weight of two-horse cars of this kind ranges from 25 to 36 cwt.; and the cost from £150 to £200, the exact price being determined not only by the size of the car but by the nature of the fittings, ventilators, cushions, lamps, stoves, and other accessories. Cars having only inside seats generally measure about 9 ft. 6 in. from the ground to their highest point and a corresponding headway is necessary under bridges which cross the track.

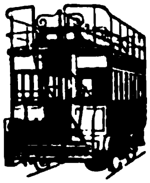
Two-horse cars.



78.

Headway under bridges.
See page 166.

In climates as cold as those of Great Britain, Russia, and the northern parts of France and Germany, cars entirely open are seldom used, except occasionally as workmen's cars at low fares; but as in such climates omnibuses with outside seats are customary, tram-cars are also constructed to carry passengers on the roof, there being generally about an equal number of seats inside and outside; the total number ranging from about 36 to 56. Thus in Berlin there are cars with seats for 56 passengers, while in London the cars are generally made about 16 ft. long, weigh from 45 to 55 cwt., and have at most seats for 46 persons, crowding beyond the prescribed number being prevented. Such cars cost from £160 to £200. In London, the cars measure about 11 ft. 6 in. from the ground to the topmost hand-rail, and a minimum headway below overhead bridges of 13 ft. 6 in. is necessary even for seated passengers; but 16 ft. is required



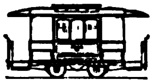
79.

Outside seats.

for the safety of passengers who might stand up. The extra weight of outside seats and passengers renders such cars unsuited for horse tramways with steep or frequent gradients; but as mechanical traction becomes generally adopted, it is probable that heavily-loaded cars will be more common. When experience has been gained in the working of a tramway, economy may be greatly promoted by choosing—as the periods of renewal occur—cars of a size suited to the average number of passengers, so avoiding the unremunerative haulage expenditure, which the use of large but only partially-filled cars involves.

Classing of Passengers.

One-horse cars are sometimes constructed to carry two classes of passengers; such cars having room for four of the lower-fare passengers at each end, and six or eight high-priced seats in the interior. Outside seats afford facility for classing the passengers, so rendering the tramways useful and popular among a mixed population. In some Continental towns the cars are divided into 1st, 2nd, and 3rd class, and even occasionally 4th class at very low fares for workmen. Even during the winter, in St. Petersburg, passengers travel at the lower fares outside the cars; but in some places where the cold renders outside seats unpopular, but where the traffic is great and a level road allows easy traction for heavy loads, two-storied cars are used in the winter, the upper tier being enclosed with sides and windows somewhat in the same way as are the two-storied carriages on the suburban railways of Paris, and elsewhere. In Bradford, Huddersfield, and other busy towns, tram-cars of this kind (81), hauled by little locomotives (88), are used at all seasons, the upper story forming a smoking carriage. These cars are unsightly, and tend to prejudice the public against the tramways which adopt them. Tram-cars of this kind are also used in Hamburg and Copenhagen. and are sometimes made so that the cover of the outside seats may be removed in the summer. In Christiania (Norway), where the tram-cars are in winter stopped by the snow, and where the non-employment of the men and horses would cause serious loss, one-horse cars (82) are placed upon sleigh runners (83) with two horses attached, the cars running only half as frequently as in summer, but at a double rate of fares. A peculiar type of tram-car which has been used in some Russian towns has already been referred to on page 299, as allowing a narrow interway between the two tracks, there being no projection on the closed side. The car, which is 15 ft. 9 in. long and 6 ft. 5 in. wide, is



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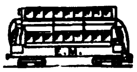
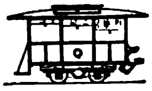


81.

Two-story cars.



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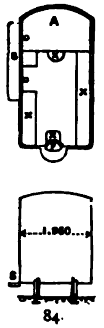
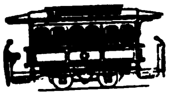
83.



84.

entirely closed at the ends and at one side, so that there are no through draughts. About two-thirds of the car contains seats, x, and one-third, A, is a covered platform for smokers, O O are sliding doors, and F is the driver's seat. The car, which has a short wheel-base, is turned (without the horses being detached) at the end of each journey, on a small turntable sunk on the track.



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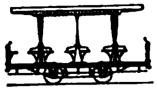
86.



87.

Cars for cable and electric lines.

Cars with outside seats on the roof are seldom used in hot climates, like those of India, South America, Spain, or Italy, though occasionally outside seats with awnings are employed; but in some of these countries, during the hot seasons, the car windows are removed, louvre-blinds (85) being sometimes substituted, and the cars are so made that the body may be in summer removed from the platform, and seats covered by an awning substituted. Cars with a roof only (86), or even quite uncovered, are used in summer (often specially as cars for smokers) in Italy, Spain, South America, and elsewhere; awnings and curtains being provided as a shelter from the sun; and in some Italian cities none but open cars are used. The seats of open cars are usually arranged *vis-a-vis* across the car (87), and sometimes, where the traction is easy, such cars are made as long as 25 ft., weigh about 32 cwt., and seat 40 persons; but more often the length is from 12 ft. to 18 ft., the seats from 16 to 32 in number, the weight from 20 to 30 cwt., and the cost from £100 to £140. Cars for cable lines cost about £20 more than horse-cars carrying the same number of passengers. For electric trolly lines the cars cost, including the motors on them, from £600 to £800 each.

Packing for export.

See page 445.

Deck cargo.

For export, the wheels and platforms can be placed inside the body of the car, which is generally packed as a whole in a large case; though sometimes, if the wheels be fitted to the axles, they are packed separately. The freight is always by "measurement" tonnage, or at special rates, the dimensions being approximately ascertainable by an allowance of 3 in. on all sides of the car, and when because of the bulkiness of the packages they have to be carried as deck cargo, high rates of freight are sometimes demanded. The packages add about 5 per cent. to the cost of the cars.

As the number of cars depends not on the length of the line but on the number of passengers to be carried, there is no particular relation between the expenditure on the fixed works of a tramway and on the rolling stock. The Broadway line in New York probably

See page 319.

affords the best example of numerous cars (40 to 60 per hour), in proportion to the length of line.

Horsing of cars.

6. *The Hauling of the cars either by Horses or Mechanical traction.*—Haulage by horses finds its best opportunity where there is a level track, moderate traffic and where cheap forage is obtainable. Under such conditions, and where a ten-minute service is sufficient, it may be inexpedient to incur the capital cost for mechanical haulage which, under any other circumstances, almost always presents great advantages.

Conditions of good management.

Horse mileage per day.

Effect of gradients. *See page* 301.

Care and judgment are necessary to maintain horses in a state of efficiency and to obtain from them the maximum of service. Sufficient and suitable food, clean, well-lighted and well-ventilated stables, careful shoeing, a not excessive amount of work, and regular rests are the necessary conditions. The mileage which the horses can work in a day depends, of course, on the weight of the cars and the gradients. In London a two-horse tram-car, carrying 44 passengers and running 70 miles a day, usually requires 10 horses, each horse when thus working its full distance having 14 miles of work. But to maintain this service 12 horses have generally to be provided so as to allow for occasional rests, and still more are required if for the surmounting of hills one or even two additional horses are required occasionally along the route. So greatly is the resistance of the car increased over that presented on a level that even the addition of two horses may not neutralise the effect, and if the hills are more than 100 yards long, the extra exertion tells severely on the endurance of the horses.

Two-horse cars.

Working life of horses.

Where two-horse cars are limited to 30 inside passengers, and the track is level, the horses are often worked 16, 18 and even 20 miles a day. The London General Omnibus Company, by careful selection of their horses and careful treatment, raised the working life of the animals from three and a half to five years. In the working of tram-cars the brakes save the horses from the severe strains in stopping which used to tell so severely on omnibus horses before efficient brakes were introduced; but this advantage is more than outweighed by the severer strains the tram-horses constantly undergo in starting the cars; the rails affording but slight assistance in overcoming the inertia, which is greater for the loaded tram-car, because of its greater weight, than for the omnibus.

When the first tramways were opened in London in 1870, the cars weighed from 2 to 2½ tons, carried 40 and 46 passengers (inside and on the roof), and were drawn by two horses. The horses were provided by the General Omnibus Company at a hire rate of 6¾*d.* per car mile, this including all charges for stabling, harness, maintenance, and labour, up to the moment of attaching the horses to the car. Later, when the tramway company provided their own horses, the cost was brought down to 5*d.* per mile, but while this covered all current charges, including a depreciation or renewals rate of 20 per cent. per annum, it did not include any interest on the capital expended in the first purchase of the horses and the erection of stables.

Cost of horsing.

Rate per car mile.

Each horse cost 18*s.* per week, of which 10*s.* was for provender; 4*s.* 2*d.* for wages and expenses of stable and granary; 1*s.* for shoeing and repairs to harness; and 3*d.* for depreciation and renewals. Any statement of the cost of horsing per car mile is, however, incomplete unless the gradients, the weight of the car, and the number of passengers be also stated. The rate then fluctuates with the current price of provender. To allow of comparison with other systems of haulage, it is necessary to reckon the cost per passenger mile.

Cost of maintenance.

In many countries mules are used in preference to horses, and a considerable number of Spanish and American mules were at one time imported into Great Britain. Later, mustangs (a special breed of small horse) have been imported from America and have been found serviceable.

Mules and mustangs.

The rapid increase in the number and extent of tramways since their first introduction, the difficulties presented by steep gradients, the slow speed and the large proportion which the cost of horsing bears to the total working expenses, soon led to the use of Steam-engines and other mechanical means, and it may be said that up to the year 1895 none of them were entirely satisfactory. Up to the year 1897 almost all the tramways in London, Glasgow, Manchester, and Liverpool were worked by horses.

Substitutes for horses.

Steam locomotives, or their counterpart the self-contained steam passenger cars, find their best opportunity on town tramways having a large proportion of their length in suburban or open country districts, where the other and ordinary traffic of the streets is very small. As compared with horses, or any form of electric traction, these locomotives work cheaply and effectively. But they are objectionable in crowded cities. The nuisance of smoke and steam, which cannot be entirely hidden, and the frightening of horses, are

Steam power.

drawbacks which have been exaggerated, but they carry weight in any comparison.

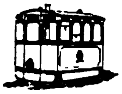
Steam cars.

The principal differences in the various steam-engines which have been tried on tramways, consist in the modes of separating the engine from the passengers. In some cases the engine is on the car, shut off from the passengers by a partition; but in regard to the objections sometimes raised against this close contiguity, it is probable that passengers would by use become as indifferent as in the almost similar circumstances on a steam-boat. Although smoke is prevented, an awning is necessary to protect passengers riding on the roof from the fumes from the chimney. In other cases a separate or locomotive car, boxed in to hide any appearance of machinery or steam, is used for hauling the passenger-car; the capacity for hauling a second or trailing car being common to both kinds of steam-car, according to their power and adhesion, and the gradients. Each presents some advantages. The combined car occupies less room in the street, and the weight of the passengers is effective in giving adhesion to the engine wheels for overcoming gradients; in the detached locomotive the engine and boiler are more effectually separated from the passengers, and can be immediately detached for repairs. Smoke is avoided by the use of coke or other suitable fuel, and in order to avoid noise the exhaust steam, instead of being discharged directly into the air, as from a railway locomotive, passes through a coil of pipes so laid in an open tray on the roof, and exposed to the air, as to serve as a surface condenser. There is no cooling water, no vacuum is formed, and the slight back pressure due to the impeded exhaust is disregarded.

Locomotives.

Steam haulage on English lines.

In England steam tramways have been worked by the separate locomotive car, for example at Birmingham, Stockton, Leeds, Huddersfield, and Bradford (where some of the passenger cars are heavy and two-storied), and on some of the suburban lines of London. Combined steam cars have been adopted in Berlin, Brussels, Stockholm, Moscow, and other important cities. The separated locomotives hitherto tried, boxed in to resemble small cars, weigh from 4 to 8 tons, and cost from £500 to £900. On some of the Birmingham tramways the steam locomotives weighed 13 tons, for they were specially weighted to obtain the necessary adhesion for overcoming steep gradients. The self-contained steam passenger cars, for 40 to 60 passengers, weigh from 6 to 10 tons, and cost from £800 to £1200.



88.

Cost of steam cars.

Steam and horses compared.

The capital outlay for horses and that for steam-cars does not differ very much, the advantage which the use of steam allows being in speed and in the cost of working and maintenance; for though the cost per car mile is generally more with steam than with horse traction, the steam-car carries more passengers. A decision in any particular case depends very much on local circumstances; for instance, where horses or mules are plentiful, and coal dear (which conditions are found, for example, in some South American towns), it would seldom be expedient to bring steam-cars and drivers from a distance, especially if the gradients be easy. The longest tramway in the world is that starting from Buenos Aires and extending 240 miles. The cars are drawn by horses, and the journey occupies 2½ days. As in horse-cars the strains in stopping and starting are the severest for the horses, so in steam-cars the fuel expended in each stoppage bears a large proportion (estimated by some engineers as equal to that for half a mile of haulage) to the total consumed. For this reason, and also to allow of safe crossing places for foot passengers, the plan of stopping only at appointed places is sometimes adopted.

Long distance horse lines.

Among the substitutes for steam-cars, but still included in the category of those having self-contained power, are the cars which derive their force from Gas or Oil, as well as those carrying Electric storage batteries, or a reservoir of Compressed air.

Gas and oil fuel.

Gas motors.

Gas has been successfully used for self-contained motor cars, as, for example, in Germany at Dessau and Dresden, and in England at St. Ann's, Blackpool. The gas is taken at a normal pressure from the town mains, and compressed at the terminal station to about 120 lbs. per inch, and then delivered by an ordinary flexible tube to small cylindrical reservoirs hung under the car. Reckoning the consumption in the uncompressed gas, from 30 to 50 ft. are consumed per car mile according to load and gradients, this quantity including what is necessary for the compressing engine at the station. A journey of 7 miles can be made without recharging. A two-cylinder engine of the Otto type is employed on each car, and this with all its gear is compactly arranged below the car. A certain quantity of water is carried, which circulates through the water jacket of the cylinders and through cooling pipes on the roof. As a gas-engine cannot be started quickly, the motor is kept constantly running while the car is in service, and the stopping and starting of the car are effected by friction couplings connecting the motor engine to the car wheels. The car complete costs about

See page 602.

Cost of gas motor-cars. £600, but if made powerful enough for hauling a trailing car, the cost is about £700.

Oil motors. *See page 606.* Where gas is not obtainable, Oil vaporised can be used as gas, but there is the same need as with gas for cooling water, and the additional inconvenience of unpleasant odours not easily overcome. The oil occupies less storage space than the compressed gas.

Compressed air motors. *See page 496.* Compressed Air has been used for tram-cars, as, for instance, in Paris, and where the compression machinery is already provided for other purposes, or where mains from such compressors are accessible along the route so as to allow frequent charging of the reservoirs on the car, the system is feasible. Analogous examples are found in mines, where compressed air primarily provided for rock drills, is used also for locomotives or for pumping in the underground galleries, as well as for ventilation. Where, however, other systems of power transmission are available, it is seldom that compressed air compares favourably with them either in regard to convenience or economy.

Electric accumulators. *See page 269.* Electric accumulators or storage batteries carried on the car can, by means of a dynamo motor such as is used on the car of an overhead trolly or conduit tramway, give out force along the route sufficient for haulage on a level track, but it is practically impossible to haul heavy cars up steep gradients or to haul a second or trailer car. Storage batteries have been much improved since 1890, and a set of such accumulators can be constructed with a weight equivalent to about 100 lbs. per horse-power hour. It may be assumed that for a five hours' storage the accumulators will weigh about as much as the persons carried, and the car as much as the two put together. As an example, if 50 persons weigh 6000 lbs., the storage batteries would weigh also 6000 lbs., and the empty car with its motor 12,000 lbs.

Storage batteries costly. The use of electric storage batteries has not proved economical, and should only be adopted where other methods are more than usually difficult. Although they allow of concentrated force, so that for instance a set of batteries capable of giving out an average of 8 horse-power for a specified time may be made to give out 20 horse-power for a momentary effort in starting a car on an incline, such concentration, if often applied, tends to more rapid deterioration than where the force abstracted is uniform. The jolting of the car and the frequent changing of the batteries have also an injurious effect. From both these causes the batteries do not last so long as those remaining in one place, and giving out when in operation a constant force as for electric lighting. Storage batteries weigh from 100 lbs. to *See also page 269.*

130 lbs. per horse-power hour; the current for recharging would cost about 4*d.* if a small electric installation were provided for the purpose, but 2*d.* if the current of an electric lighting plant be utilised in the daytime.

See also page 278.

Leaving now the systems of mechanical haulage where the force is carried with or on the car, those in which power generated by a fixed engine at a central station may be considered.

Cable haulage.

An endless, constantly-running rope or Cable driven by a stationary engine, and to which the cars can be connected at will, does not impose so heavy a load upon the rails as do locomotive cars which contain motors or machinery, and which depend for their tractive force on the bite or adhesion of the driving wheels. The permanent-way may therefore be made lighter, and there is less abrasion on the rails. The cable system was first introduced in San Francisco to overcome gradients too steep for horses, and the convenience it afforded for utilising the power of a fixed engine led to its adoption in cities, even where the gradients did not prohibit other kinds of traction.

Favourable opportunities.

The cable finds its best application where there is a busy traffic requiring a frequent service of cars, where the curves are few and of easy radius, and the system compares favourably with others where there are numerous or steep gradients. The endless rope is an old method of hauling carriages on a rail track, and was in use before the introduction of railway locomotives. The running rope was especially employed for hauling carriages up inclines both above and below ground, and it is still a convenient and much-used method of haulage in mines. In London during the years 1840–48, the passenger carriages on the Blackwall railway (an almost level track), 6 miles long, were drawn by an endless hempen rope to which the cars were connected by a grip under the control of the car conductor or driver. There is the obvious advantage that an endless rope provides for vehicles in both directions, and on gradients, however steep, not only allows the same speed as on a level, but utilises the gravity force of the descending cars to balance the weight of those ascending. These conditions are, as an extreme example, in operation on mountain railways and for surmounting, by inclines as steep as 45°, the slopes from a sea or river level to the tableland above.

Early examples.

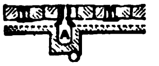
Advantages.

Cable haulage described.

On a modern cable tramway an endless wire rope, worked by a stationary steam-engine or water-engine at the terminus or some convenient place along the route, runs at from 6 to 12 miles per hour in a trough, made wholly or in part of iron, just below the centre of the track.

Rates of speed.

The lower speed is that permissible and usual in crowded streets, and the higher speed in suburban districts. The trough is entirely closed at the top, except that in the covering plate there is a groove or slot ¾-inch wide, through which a bar or finger, armed at the end with a knuckle joint or grip, projecting downwards from the car, grasps the rope, the grip being relaxed when it is desired to stop the car. The car obviously cannot move quicker than the rope unless the driver, when on a down gradient, releases the grip and runs at a high speed by gravity force, a method which, though under control of the brakes, is forbidden not only because of the possible danger, but because the weight of the descending car is then not utilised to aid the ascending cars. The driver can, however, by slightly slackening the grip as occasion arises, let the rope slip past, and so reduce the speed of the car below that of the rope. This control is, however, too damaging to the rope to be used where it can be avoided, and it is better to divide the route into two or more sections, and to have separate cables with appropriate speeds for each.



89.

Amount of force required.

On a straight road from 40 lbs. to 50 lbs. of tractive force are required per ton of cable without any cars attached, but the resistance rapidly increases for each curve on the road, the additional friction and the risk of damage to the rope becoming greater as the radius of the curves is reduced.

The cable system is the most expensive to construct, and has suffered in repute, not only for this reason, but also by the inconvenient failures and accidents of the earlier installations. The capital cost is great, owing mainly to laying the trough or conduit and machinery below ground. The conduit in the centre of the track had to be 24 in. deep and 18 in. wide, and the excavation still larger, to allow of the trough being fixed.

Inconveniences.

Breakage of the cable, and the consequent stoppage of all the cars, was in the earlier tramways a frequent cause of inconvenience, and it arose largely from excessive hardness of the rope, and from its disruption by passing round curves of small radius and badly arranged pulleys. The rumbling noise of the constantly running rope, though it is imperceptible amidst the street traffic, becomes more audible during the evening hours, and has sometimes been deemed a nuisance during the hours before midnight by those living on the line of route. The occasional fractures of the rope, and the noise, were not deemed vital objections to what was, in other respects, a great convenience. It was the high capital cost, the excavations below the road and surface, and the limit of speed, which were the main reasons that induced a change, when the overhead electric trolly system became available in the United States. In short, the cheap and speedy construction and the desire for quick transit were the reasons, and when the trolly system was introduced it superseded many of the cable roads in the United States. The capital outlay for some of the latter had been as high as £60,000 per mile of double track, where electric trolly roads have since been made for £20,000. Subsequently, however, the drawbacks and dangers of electric tramways also became evident, and as the details of the cable equipment were, under the stimulus of competition, much improved and cheapened, it again took a place as one to be considered, and, under certain circumstances, preferred to all others, at any rate till the available systems of electric haulage become much improved.

See page 320.

Cable tramways costly.

Improvement in cable haulage.

Steel wire rope is now made of various kinds according to its purpose, and that with a hempen core which has proved flexible enough to pass round pulleys and drums of small diameter as in cranes and other hoisting machinery, will serve also for cable tramways without the great risk of failure that attended the use formerly of hard solid ropes. The usual diameter for tramway haulage is 1⅛ in. or 1¼ in., weighing 12 lbs. and 15 lbs. per fathom respectively. In the case of a tramway 3 miles long, the rope, if 1⅛ in. diameter, would be rather more than 6 miles long and weigh about 29 tons. In the favourable case of a straight track without curves, the force necessary to move the rope at the rate of 10 miles per hour should not be more than 40 lbs. per ton, or 1160 lbs. in all, equal to 31 horse-power. Gradients will not have much effect, but numerous or sharp curves will so increase the resistance that in some lines, unfortunate in these respects, as much as 200 lbs. per ton is required, equal to 155 horse-power, for a rope of the above length and weight. On a service requiring 10 cars per hour, and assuming that for each car carrying 80 passengers and weighing 7 tons a haulage force of 140 lbs. be required, or 1400 lbs. in all additional to the rope haulage, then if the latter be taken at 100 lbs. per ton of rope it will be seen that more than half of the total force is employed on non-paying work. But if the number of cars be increased to 40 per hour, as on the Broadway line in New York, then the proportion of paying work would be two-thirds of the whole. Too much importance is sometimes attached to the item of power, which does not form a large proportion of the total working expenses. In

Flexible ropes.

Weight of cables.

Power required.

Cable system effective for busy traffic.

Birmingham, for instance, it was in 1898 only one halfpenny per car mile. On the Brixton line, in London, there is a one-minute service, and on the Edinburgh line a 3-minute service; and on all these lines, as well as at Melbourne and Sydney, there is a remunerative return on the capital invested, although the rates of fare are very low.

Improvements in cable lines.

Considerable improvements have been made in the troughs or conduits, and much narrower and shallower excavations have to be made below the roadway. The more flexible ropes and the better designed pulleys give a life of from 300 to 500 days to the rope, while on the earlier American lines the life was from 30 to 80 days. The cable system is most remunerative when during busy traffic one or even two trailer cars with one attendant each are added to one grip car, which requires two men. Such trains are not allowed in Broadway, New York, but cable-car trains of three run regularly during busy hours in Chicago. Whatever may be the demerits of the cable system, the working expenses have proved lower per car mile and passenger mile than those of any other system in almost all cases where the service of cars is not less than 20 per hour. This economy compensates for the higher capital cost of the cable roads as compared with that of other systems.

Electric trolly system.

The Overhead trolly System of Electric traction was between 1890 and 1898 used on a longer mileage than the aggregate of all other mechanical systems. In this regard it found its earliest and chief development in the United States, where 12,000 miles (reckoned as single track) were in 1895 working out of a total tramway mileage of about 14,500.

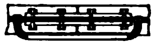
Cheap and quick.

The cheapness in first cost, the increased speed, and the ease of operating in cities free from restrictive safeguards enforced in Great Britain, were among the circumstances that led to this great development. For in cities badly paved and without the numerous omnibuses and cabs available in Europe, the need for cheap quick transit outweighed the inconveniences.

Trolly system described.

The current is generated at a central station to a pressure of from 2000 to 3000 volts, and is taken on overhead conductors along the route. At intervals of from 600 to 800 yards the current is transformed down to 500 volts, and fed into the smaller conductor-wires suspended over the track, and from them to the motors under the cars by light rods projecting from the roof, which holds a metallic trolly running on the wire. In some cases the overhead conductor is a tube, within which a small bar running on copper balls is dragged along by a flexible cord attached to the car. The return current for completing the circuit is

See page 287.



Plan of rail showing Electric Bonding.

taken by the rails, which must be bonded with copper (*x x*) to ensure continuity. It is difficult to maintain contact between steel and copper owing to oxidation, and elaborate means are taken to ensure it. With these facilities, a force of 25 or even 50 horse-power is obtainable in each motor car, so that not only can heavy loads be started on and taken up steep gradients, but a trailer car can be added when the traffic requires it. The rule which generally prevails in mechanical or industrial operations, that increased demand and increased output allow greater economy of working, needs qualification when applied to electric systems of haulage. For if the main conductors be not constructed from the beginning for the maximum traffic, any increase in the consumption of current rapidly increases resistance, and renders the cost of working proportionately higher than before. Moreover, if more cars are run simultaneously upon any one section of the line than the trolly wires can supply at normal pressure, there is also an increased resistance.

Powerful motors on car.

Drawbacks of the trolly system.

The trolly system, as above described, and as worked in the United States, afforded a great convenience, not only in large cities, but in newly settled districts where the tramways preceded and assisted the development of the towns. But numerous inconveniences also arose. The network of overhead conductors not only disfigured the streets, but became a positive source of danger, owing to inadequate insulation and accidental contact with telegraph and telephone wires. Guard wires under the conductors to catch them if they broke proved only partially effective, as they often completed a circuit and themselves transmitted a dangerous current to passers-by, or were fused and fractured. The wires also formed a dangerous impediment to ladders and hose pipes in cases of fire. The electrolytic action of the return current on gas or water pipes has been a cause of inconvenience and damage.

Dangers.

Safeguards.

One safeguard adopted to minimise these evils was the better insulation of the main conductors, and the laying them in conduits below the ground at the side of the streets, and from these mains feeding the overhead suspended wires on which the car trollies worked. The losses from electrolytic action at first proved inconvenient and costly, but they were partially overcome. The careful bonding of the rails and safe earth connections were the chief remedies. In European cities, when the advantages of the trolly system were desired, light and elegant poles, generally composed of steel tubes, were erected, as at Milan, Havre, Bristol, and Leeds.

Electrolytic action on pipes.

Steel poles.

Conduit trolly system.

Objections to the poles and overhead wires led, however, to various substituted methods as described in this chapter; and where it has still been desired to utilise electricity as a means of transmitting the power of a fixed motor to the cars, what is known as the conduit system has been adopted. According to this, not only are the main conductors taken underground (which is also possible with the overhead trolly system), but the contact conductors are laid in conduits below the centre of the track, contact being obtained by a finger or bar projecting downwards from the car through a slot in the plate which covers the conduit. This method is more costly than the overhead trolly system, partly from the greater interference with the road surface, in which respect it about equals the endless cable system, and partly from the outlay for the conduits and accessories. Although there are no insurmountable mechanical difficulties in this arrangement, there have been difficulties in regard to insulation and induction which are more serious. The conductor is necessarily exposed so as to afford a continuous contact with the car, and although the occasional supports on which it rests are insulated, the rain and mud and snow which may enter from the road surface through the slot, or ice which may form on the conductor, destroy or diminish the insulation and cause leakage of the electric current. The risk of injurious electrolytic action on underground pipes and other metallic structures proved to be greater than with the overhead trolly lines. The conduit system finds its best application where there is only light street traffic, and where the streets are kept clean. Thus it proved feasible in the suburbs of New York, though not in the centre of the city. Since 1895 the electrical difficulties have been so far overcome as to indicate that some form of conduit system is likely in the future to prove the most convenient system, where the interference with the street paving and the higher capital cost can be afforded.

More costly than overhead lines.

Leakage of current.

Board of Trade rules.

In Great Britain the Board of Trade in 1893–4 established rules for regulating the employment of insulated returns or of uninsulated metallic returns of low resistance; for preventing fusion or injurious electrolytic action of or on metallic pipes, structures, or substances; and for minimising, as far as is reasonably practicable, injurious interference with the electric wires, lines and apparatus of parties other than the tramway company, and the currents therein, whether such lines do or do not use the earth as a return. One of the most stringent of the rules in restricting the free action of the tramway company is that which

Summary of regulations.

prescribes that "the insulation of the line and of the return when insulated and of all feeders and other conductors shall be so maintained that the leakage current shall not exceed one-hundredth of an ampere per mile of tramway." In the interests of the owners of wires which may have been erected or laid before the construction of the tramway and in the same direction, special precautions are prescribed for preventing disturbance by electric induction. Besides the general rules above referred to, special regulations are included in the Provisional Order under which each particular tramway is authorised in regard to the working of the line. These refer to brake power, to the speed of the cars—generally 8 miles per hour as a maximum and 4 miles in busy streets—and prescribe electric governors which shall automatically cut off the current if a speed of 10 miles per hour be exceeded. Only one trailer car is permitted. The suspended conductor must not be at a less height above the street than 17 ft., and shall be securely attached to supports at intervals not exceeding 120 ft. The electric current through it must in no case exceed 500 volts continuous pressure. No part of any electric line shall be used for the transmission of more than 300,000 watts, except with the special consent of the Board of Trade for satisfactory reasons. Efficient guard wires must be provided to prevent contact of the electric conductors with telegraph or telephone wires. There are also bye-laws which apply to all kinds of tramways.

Local regulations.
See also page 290.

Bye-laws.

Cost of tramways.

7. *The Cost of Construction* has been omitted from the preceding description of the various kinds of tramways because, whatever may be the method adopted, a considerable proportion of the total cost depends on local circumstances, or on those common to all tramways. It may be convenient, therefore, to deal with these points separately. The inception of a tramway undertaking, the obtaining of a concession or of other authority, the formation of a company and raising capital, are all matters involving outlay of money quite beyond and outside the actual cost of construction. From £200 to £2000 are limits not too wide to include the actual outlay for these purposes in the majority of cases in Great Britain, but the larger sum has been occasionally exceeded, especially when great opposition has been encountered.

See Chap. I.

Land and buildings.

The necessity for the purchasing of land and its cost if purchased are local incidents not depending on the kind of tramway. Stables for horses, covered sheds for cars, power-houses or other buildings may sometimes be erected on land held on rent, the payment of which may be set against the saving in capital. The conditions imposed by the street authorities in regard to paving differ widely, as they depend mainly on the standard already established or on the exigencies of the ordinary street traffic. Leaving out the preliminary expenses above referred to, and excluding any purchase of land, the following are approximately the cost of different systems. The rates given are per mile of single line, so that an addition would have to be made wherever a side track is required as a passing place. About 80 per cent. would have to be added to arrive at the cost of a double track. The exact cost in each case within the wide limits given, while depending primarily on the exigencies of paving and interference with the road, also depends on the strength and quality of the line.

Paving. *See page* 306.

Cost reckoned at per single line.

Horse tramways.

A tramway for horse-cars with rails 60 lbs. per yard, including all equipment except cars and horses, would cost from £6000 to £10,000 per mile of single track, the exact price within these limits depending mainly on paving. With girder rails of 100 lbs. per yard and a strong road bed, the cost might rapidly increase to £12,000 per mile. Including the outlay for cars and horses, and all preliminary expenses, the capital expended on the horse tramways in London has averaged £30,000 per mile of double track, some lines having cost as little as £22,000 and some as much as £40,000.

If suitable for steam locomotives or for any kind of self-contained motor car, the cost of the tramway would exceed that of the horse line by about £2000 per mile of single track.

Cost of trolly lines.

An overhead electric trolly line complete, with power-house and all except cars, would cost £8000 to £12,000 per mile of single line, while a tramway on the conduit system would cost from £15,000 to £20,000 per mile.

Cost of cable lines.

A cable tramway (double line), including all equipment except cars, would cost from £35,000 to £50,000 per mile. Some cable tramways have exceeded this estimate, and, owing to the great expenses connected with the underground construction, have cost as much as £60,000 per mile of double track, exclusive of cars. But in comparing costs it must be remembered that while the cars for the electric line cost, with their motors, from £600 to £800 each, those for the cable line cost less than £200.

Revenue of tramways.

8. *The Revenue.*—In estimating the earning power of any projected tramway, the rules and conditions under which it is to be

worked have to be taken into account. In Great Britain and in most Continental cities there are stringent statutory and municipal regulations as to the speed and the number of passengers per car, and also as to the rates of fare. In most American cities crowding is allowed within wide limits during the busiest times of the day, and cars which are arranged for 30 passengers will carry 60 persons; and the fare for any distance is, with very few exceptions, five cents (2½*d.*). In Glasgow and Edinburgh the tramway routes are divided into sections, for each of which a fare of only one halfpenny is charged. In London and other large cities the fares are about 1*d.* for stages of one mile; but where, as in London, the tramways have to stop at the "city" boundaries and at the Thames bridges, omnibuses, generally with one horse, convey passengers at a halfpenny fare from the tramway terminus for about half a mile onwards. The experience gained in the working of tramways in different countries shows that a remunerative return for the capital outlay has generally been obtained when not more than 80 per cent. of the gross earnings is consumed in working, administration, and maintenance. On English railways it has been found that some percentage between 50 and 55 is generally the highest which will allow a surplus sufficient for a fair dividend; but the cost of land and works is generally much greater than on a tramway, and the earnings per car per mile very much less; so that a larger portion of the receipts on a railway must be applied to meet the interest on the fixed capital. The actual working expenses of tramways, including maintenance and depreciation of plant, range from 60 to 90 per cent. of the gross income, and a large revenue may justify a high capital cost. If current repairs be done effectually out of revenue, a depreciation rate of about 3 per cent. generally covers the reduction in value. At the end of 1896 there were, in the United Kingdom, 1469 miles (reckoned as single lines) in operation, and the actual capital outlay had averaged £10,347 per mile. The gross receipts per mile for the year 1896 averaged £2827 per mile, and the working expenses, ranging from 9*d.* to 12*d.* per car mile, £2114. The apparent net revenue of £713 per mile was not, however, necessarily available for dividend, especially where the expenditure for maintenance did not wholly cover depreciation nor provide sinking fund.

Crowding of cars.

Rates of fare.

Percentage of working expenses.

See RYS, *page* 70.

Working expenses.

Gross receipts.

Net revenue.

In the large cities of the United States the gross receipts and the expenses are both higher than in Europe, and in some cases where the franchise has been obtained on easy terms, where the obligations for road paving are also easy, and where there are no restrictions on the crowding of the cars, larger profits have been made than are possible on European lines.

Obligations, privileges, and bye-laws.

9. *Minor Obligations, Privileges, and Bye-laws.*—Certain obligations are imposed on the proprietors or lessees of a tramway besides those already described. Such are the maintenance of a regular and sufficient service; the rates of speed; the cleanliness of the cars; and stipulations as to the temporary stoppage or diversion of the track to allow of access to sewers or pipes. Other conditions are sometimes demanded by the authorities, such as, that cars shall be run at early hours at low fares for workmen; that firemen, postmen, and telegraph messengers shall, when on duty, be carried free; or that the free use of the line shall be allowed in the night for municipal cars containing road materials, sewage matter, or refuse. Demands of this kind obviously depend on the local circumstances or necessities of each case. Thus, for instance, in Berlin the military authorities have stipulated for a free right of way for ambulance tram-cars over those lines which connect the barracks and the hospital.

Officials carried free.

In the concessions or charters which authorise the establishment of tramways, certain secondary privileges are necessary in the interests of the proprietors, besides those which convey the monopoly and right of way. These privileges are sometimes specified in the concession or enactment by which the tramway is authorised; but sometimes many of them are left for embodiment in bye-laws drawn up and published by the managers of the tramway, with the sanction of the police or municipal authorities. Such regulations, or bye-laws, define the times and conditions under which the roadway may be blocked for repairs to the tramway, and forbid the obstruction by ordinary vehicles of the passage of the cars. In some countries, as in Great Britain, there are laws which apply in certain matters to all tramways, and these generally are for the safety of the public. Other regulations, already referred to, are framed for the comfort of the passengers, and refer to such matters as overcrowding on the cars and unnecessary halting. Powers are generally given to the tramway company for the recovery of penalties for infringement of the bye-laws.

Protective rules.

Safety and comfort of passengers.

Tramway projects.

As conveyed in the foregoing pages, the Cost of a tramway, the choice of materials and equipment, and the probabilities of Profit depend entirely on the local circumstances of each case; and in the following summary are recapitulated those particulars which must be furnished to allow of the proper consideration of a scheme by engineers and capitalists.

Particulars enumerated.

(1) A *Map* of the city or town and its suburbs, showing the streets, railway stations, markets, and public buildings, the routes of existing tram or omnibus lines, and the proposed routes for the new tramways.

(2) The *Population* of the town and suburbs, and statistics as to the growth of population.

Maps and plans.

See BRIDGES, *pages* 137 *&* 166.

(3) *Plans* and *Sections* of the tramway route, showing the width of the road and foot-paths at all points, and the Gradients. Over bridges with their headway, and under bridges with the gradients of the approaches, should be plainly delineated. A description of the buildings and shops along the whole route should accompany the plan.

Street paving described.

(4) A description of the *Streets* in regard to the kind of paving and substratum, the method of draining, and the order in which the surface is kept, together with the method adopted for cleansing and mending the roads; information concerning the sewers or pipes below the roadway, and the frequency of repairs, so far as these may affect the tramway.

(5) The number and kind of *Omnibuses* and cabs, how far they are sufficient for the traffic, the privileges or obligations under which they ply, the rates of fares, the number of passengers, and, as far as can be ascertained, the profits earned.

Horses.

(6) The kind of *Horses* or mules obtainable, and the prices; the cost of provender, and the current prices of coal or oil fuel.

Climate.

(7) Information as to the *Climate*; the means, habits, and occupations of the inhabitants, and the nature of the traffic between the city and the suburbs, so far as they will influence the business on the tramway, or by which the kind of cars may be determined.

Import duties.

See page 448.

(8) Information as to *Import Duties*, cost of transport, materials, and labour, so far as they may are likely to apply to tramways; and, specially, particulars concerning the kind and cost of timber for sleepers, and of materials available for concrete (shingle, gravel, sand, cement and lime), and for paving the streets.

See Chaps. I., II.

(9) The *Conditions* under which a concession has been, or may be, obtained, the restriction, if any, in regard to the system of haulage, with the nature of any other privileges and obligations.

Tramways in country districts.

Tramways in *Country Districts* with a sparse population, and those for carrying goods, have to be regarded quite separately from town tramways. Where, however, the suburbs of one town approach very nearly to those of another, or where a town is situated a few miles from the railway station that serves it, a tramway may generally be constructed with advantage to join these points, even though a portion of the route may be along rural roads without population. Tramways for the conveyance of minerals were in operation long antecedent to railroads, and a new stimulus has been given to this branch of enterprise by the rapid extension of town lines for passengers. In Sweden, Denmark, and elsewhere tramways are continued long distances into country districts, and in Argentina the tram line, with cars drawn by horses, extends for 240 miles from the city of Buenos Aires. This subject has been dealt with in Chapter IV. under the head of Light Railways.

Long-distance tramways.
See page 80.

[*See also* CONCESSIONS: RAILWAYS: LIGHT RAILWAYS: ELECTRIC TRANSMISSION: RAILWAY EQUIPMENT AND ROLLING STOCK.]

CHAPTER XIV.

MARKET BUILDINGS.

Necessity for markets.

THE demand for increased market accommodation keeps pace with the growth of modern cities. By concentration at one place, or under one roof, the commerce in provisions, as well as the cost of transport and distribution, are made easier to the trader; a better, and generally cheaper, selection is available to the purchaser; and time is saved to all. To the municipal authorities, too, a market offers facilities for the sanitary examination of food, the inspection of weights and measures, and—where such customs prevail—the collection of taxes. The new market benefits the town by attracting the inhabitants of surrounding districts; and if railways be established, they afford the double advantage of bringing into the market traders with produce to sell and purchasers with money to buy.

Advantages afforded by markets.

See OCTROI, *page* 16.

Modern markets.

Since 1850 new and well arranged covered markets have been erected in the principal English towns, and in many of the chief cities on the Continent. The large markets for cattle, meat and poultry, erected by the Corporation of the City of London; the market halls in Manchester, Sheffield, Carlisle, Leeds and Bradford; the Halles Centrales in Paris; the markets of Bordeaux, Brussels, Barcelona, and the magnificent markets in Madrid, Santiago (Chili), Buenos Aires and the City of Mexico—all erected within the period mentioned—may be cited as leading examples of modern practice.

Examples.

Markets generally established by the municipality.

See pages 192 & 290.

Revenues from market tolls.

Increased accommodation found necessary.

Markets should be free.

Decline of fairs as trade-centres.

Equitable tolls reckon as rent.

Excessive tolls reckon as taxes.

See page 17.

The establishment or improvement of a market is almost always undertaken by the municipal authorities, and is second only in importance to sanitary works. Markets should, as fit projects for official management, rank with such works as water-supply, and before electric lighting or tramways. In many cases new markets are erected upon town lands—often upon the site of an old market—and the undertaking is free from the burden of ground-rent. Market tolls frequently form the oldest and most important source of municipal revenue; and if money has to be borrowed for the erection of new buildings, the tolls or rents may be found sufficient to pay the interest. But in some cases the need or the desire for improved accommodation induces the municipal authorities to expend considerably more than the existing income will provide for; and although a revenue greater than in the past may be expected from the improved markets, it may be expedient to wait for a gradual growth of income, rather than to impose immediately rates or tolls sufficient to defray the necessary interest on the outlay. It is to the advantage of the community that a market shall be as free as possible, not only because of the direct benefit obtained in the cost of commodities, but because there should be no impediment to the market becoming a centre or entrepôt for a widely extended trade. Railways and other improved means of communication have a double effect, for, while useful to persons going to market, they facilitate also the sending of goods directly from the producer or merchant to the customer; the results of which are evident in the gradual decline of fairs as trade-centres. Although markets will always be useful for local transactions, their outside trade will dwindle and decay if burdened with charges or troublesome restraints. So long as the tolls demanded (considering, of course, the conveniences afforded) do not exceed what a free competition outside the market would produce, the revenue may be considered only as fair rent; but if by stringent regulations imposed on outside traders, or by the granting of monopolies or privileges to the stall-holders inside the market, free competition is prevented, the higher revenue so obtained becomes in effect a tax on commodities, which involves many of the evil effects of an *octroi* duty.

The want of markets may even be so manifest, and the anticipated revenue so considerable, as to induce capitalists to undertake the construction of the markets, and to look solely to the revenue as a return. A concession then becomes necessary, and the municipality will have to grant facilities, immunities, or advantages, to induce capitalists to embark in such an enterprise.

Concession granted. *See Chap. II.*

The gift of a free Site is one of the first methods by which aid may be afforded to the concessionnaires, and the next is the granting of a Monopoly. If no proper market buildings have as yet existed in the town, or if the new structure is to replace the only existing market, the monopoly may be absolute: the concessionnaires having also the sole right, and at the same time the obligation, of building any new market that may be required; but in the case of a large city with existing markets, the monopoly may be granted for a certain district only. In the interests of the concessionnaires, and to make the monopoly a real one, it should be stipulated that no stalls in the streets, hawking or public trading other than that in shops, should be permitted in the prescribed district; and although such a course may involve certain disadvantages to the town, they must be considered as part of the price to be paid for what on the whole affords increased accommodation and convenience. In some cases the sale of certain articles may be confined entirely to the market. Meat is sometimes in this way the subject of a monopoly, no butchers' shops being permitted elsewhere; and such a restriction, or a similar one in regard to fish, may be justified for sanitary reasons. The sanitary restrictions are often directed—frequently in connection with schemes of drainage—to the regulation of private slaughter-houses; their entire abolition, and the substitution of public abattoirs, being sometimes included in the concession for a new market. The construction of cold chambers in abattoirs facilitates such an arrangement, as meat can be stored during the hottest weather, and brought into the town as wanted. Where water-works or public fountains are already established, concessionnaires may stipulate for a gratuitous supply of water to the market; or, if this cannot be granted, for a certain quantity per day at favourably low prices.

Free site granted.

Monopoly granted. *See page 28.*

Street-stalls forbidden.

Monopoly of sale of meat.

Abattoirs.

Cold storage. *See page 336.*

Free water-supply. *See page 196.*

In many towns where octroi duties are levied, bonded warehouses may with advantage be constructed in or near the market, so that provisions or goods may be sold from sample, and the dues paid only as the goods are removed. By some such means the delays and inconveniences which always attend the collection of an octroi tax—and which are often unnecessarily aggravated by the examination at the barriers or gates of a town—may be reduced to a minimum. The maximum rents or tolls which the proprietors of the market will be permitted to charge to the stall-holders should be arranged in

Bonded warehouses for octroi collection.

Maximum rents and tolls agreed upon. *See page 36.*

advance. Such rents are generally calculated according to the size and position of the stall. For wholesale traders, inside or outside the building, the dues may be imposed according to the number, weight, or value of articles sold; and the accounts which are necessary to such a system offer a convenient statistical record of the commodities sold. It is, however, generally found better to arrange a tariff according to the space occupied; and occasionally the two plans are combined, so as to obtain, besides rent, a payment in some degree proportioned to the business transacted. Thus, in the London Meat Market, where the principal trade is wholesale, one penny per superficial foot of space per week is charged as rent, and, in addition, a toll is levied of one farthing on every 21 lbs. of goods. As the total quantity of provisions brought into the market approaches 200,000 tons per annum, the revenue from this source, even at such a low rate, is considerable. The corner stalls of a market, or those situated in a central position, are generally sought after, and command a higher rent than other stalls; but prominence of position is of less importance to the trader in a wholesale market than in a retail market, where a conspicuous display assists in attracting chance customers. As the worth of a concession will, of course, depend on the amount of revenue obtainable, and on the proportion which this bears to the cost of the market, and as mere permission to charge certain rates will be unavailing if no tenant be found to pay them, great care must be taken, by inquiry among traders, and by comparing the rent of existing markets, stalls, or shops, to ascertain what prices traders will be able and willing to pay for accommodation in the new market. Where the population is a growing one, an increase in the letting-value of the stalls in a well-placed market may be fairly expected.

Rent and tolls combined.

Corner stalls preferred by traders.

Rent of stalls regulated by rent of outside shops.

Opposition to new markets.

Opposition to a new market is not unfrequently manifested by traders already established in shops or in an existing market, who may apprehend loss to themselves from a rival undertaking; and opposition of this sort may often be conciliated or neutralised by giving the first offer of stalls in the new market to such established traders; and the same or even an earlier preference may be granted to street sellers, the stoppage of whose business it may be one of the objects of the new markets to attain. The right to establish markets is, when retained by the town authorities, considered permanent as well as exclusive; but where the privilege is granted by a concession to others, the monopoly should be for a term of years, 40 to 80 years being usual terms. If the markets are

Markets generally a town monopoly.

Length of lease to concessionaire.

to become the property of the municipality without payment at the end of the term, then it will be necessary to set apart from the revenue a sinking fund for paying back the capital; but the municipality, instead of requiring a free transfer of the property, in some cases only reserve to themselves the right of purchasing the markets on certain conditions defined beforehand. Investors, as a rule, prefer the gradual return of their capital, and, if a sufficiently good dividend be secured to them, will not be unwilling to give up their property after a certain fixed period. The supposed value of the privileges granted will determine what period will be remunerative to the concessionnaires.

Sinking-fund. *See page* 39.

Although there are various considerations of locality and purpose which differ in each case, there are certain main features or conditions which are common to markets everywhere; and one of the first and most important is that of the site, for if this be badly chosen it will, so far as the use of the market and the revenue derived from it are concerned, neutralise what in all other respects may be complete. The site of an old and well-frequented market is generally best for a new structure, as people have traditional habits in such matters, and prefer to go to an accustomed place. It is difficult to change such habits; people will continue, if allowed, to prefer old places even if in narrow and inconvenient streets; and, unless ensured by regulations which can be enforced, it is unsafe to assume that a new market will be frequented.

Choice of site.

Site of an old market the best.

A central situation, where many streets converge, is a good site for a new market, and in such cases the commerce of the market may even be promoted by making the main avenues useful as public thoroughfares for foot passengers; or, if it is sought to build the market in a public square or plaza, for vehicles also. This arrangement obtains in the London Meat Market at Smithfield, where a main street bisects the structure, passing through it under cover, and there is a somewhat similar arrangement also at Paris. If so central a position cannot be obtained, then a site between two important streets should be preferred, or, at any rate, a site where one or more entrances to the market may open, and be conspicuous from a much frequented thoroughfare. As it is an advantage to have numerous points of access and exit, entrance gates or doors should be freely provided on all sides of the building. Contiguity to railway stations, to an important bridge, or ford, or ferry, is advantageous, not only for the bringing of produce and goods to the

Central situation.

Conspicuous position.

Good access necessary.

market, but because the trade of a market is much increased when it is thus situated in the stream of traffic.

The size of markets. The size of a market in proportion to the population depends greatly on whether the business is to be wholesale or retail, for in the former case, where traders purchase in bulk for re-sale in the suburbs (as in the principal London Markets), it is obvious that a much less space will be needed than would be required for the retail disposal of an equal quantity of merchandise. **Choice of design.** The choice of design depends principally on the purpose for which the market is required, on the climate, and on the amount of money available. The simplest and cheapest kind of market buildings consists of covered sheds, or arcades, open at the sides, erected in an open space, suitably levelled, paved, drained and lighted. **Sheds or arcades.** Such structures are most suitable for fruit, vegetables, and flowers, and may be, and often are, used as general markets also; but the extent to which such an arrangement is expedient depends mainly on the climate. In warm or dry countries it may be sufficient to provide thus a shade from the sun; and such covered sheds, supplemented perhaps by awnings, are often found in continental and eastern countries. **Awnings.** **Enclosed markets.** In cold or damp climates, enclosed and covered markets are desirable; and in very hot countries, walls and roofs constructed so as to exclude the heat may be equally necessary.

Open market-place. An open market-place is often kept clear as a plaza or square; and on other than market-days is used as a place of assembly, or as a review ground for troops. Where such use of the space is frequent, portable booths of wood and canvas can alone be allowed; **Booths.** but often improvements may be made with advantage in the paving, draining and lighting. If an unencumbered space is wanted only on rare occasions—annually, for instance—light buildings may be constructed of iron and wood in such a manner that they can be easily taken down and refixed. **Removable buildings.**

In the design of a covered market, as of most other structures, it is economical and convenient to divide the area to be covered into rectangular or other regular figures of similar dimensions, and (if the site be of an uneven shape) either to leave irregular corners open or to fill them with specially designed structures. **Area of market, how divided.** **Buildings of regular shape.** By thus having the various parts of simple shape, with as little variety as possible, and interchangeable, the building can be made at a minimum cost, and will best allow of extension afterwards. *See page* 876. Such an arrangement can be carried out in various ways; if the area be large, separate but

Buildings arranged in blocks.

Fountains.

similar pavilions may be placed side by side, or grouped round a central structure; the spaces between the pavilions being used as either covered or uncovered avenues. Architectural effect may be given by making the central structure higher than the pavilions, and surmounting it with a dome and flag-staff. Another plan, if the shape of the site favour it, is to cover the area with a series of parallel roofs, as is done sometimes in a railway-station. A fountain placed under the centre of a dome, or where avenues converge, will enhance the symmetry of the design, and in warm climates be pleasant and refreshing.

Roofs of moderate span.
See IRON ROOFS, *page* 868.

Design depends on kind of trade.

General markets.

Galleries.

Useful for sale of small wares.

Or for public meetings.

Staircases.

There is no necessity for roofs of large span (which are expensive) over a market building, for as a market is properly and conveniently divided into avenues, supporting columns can be placed near together, without interfering with the circulation of persons or with the business of the traders; a market, in this respect, differing from railway stations and other buildings, where it is often very important that no columns shall obstruct the entire width of the enclosure. The details of the design depend also to some extent on the nature of the business to be transacted; whether wholesale or retail; whether for corn, meat, fish, or vegetables; or whether as a general market for all kinds of provisions. Frequently, in a general market, not only provisions but—where the space allows—all kinds of wares for domestic use are sold; and it is in cases of the latter kind that galleries are useful and profitable. As the amount of rent for stalls is measured by the area, and as galleries in a building already enclosed need not cost in proportion to their area so much as the original building, a valuable addition to the revenue may by their use be obtained. The expediency of having galleries must, however, be decided according to the nature of the commodities, the accommodation already provided, and other circumstances of the case. In some English and Continental markets, galleries are found extremely useful, and well frequented for such wares as clothing, haberdashery, seeds, hardware, confectionery, toys, and birds. As market buildings are sometimes rendered available for public meetings or performances, galleries, useful for such purposes, afford a remunerative addition to the revenue. The galleries should be continued on all sides of the building, or staircases provided at each end, and the staircases should be wide, conspicuously placed, and easy of ascent.

Where land is valuable, and where, therefore, it is desirable to

Cellars. **Access to cellars** **A sloping site utilised.** **Cold storage.** *See page* 331.

utilise to the utmost the area occupied, cellars may be provided underneath the market, and let for the purpose of storage to the traders who occupy stalls; or they may be used as a wholesale market, or may be let separately to wine merchants, potato dealers, or others. If cellars are constructed below the market, special arrangements must be made for paving, lighting, draining, and ventilating them, and for giving access to them from the market. Openings from the outside of the market to the cellars must be provided also; and in some cases it is found desirable to have sloping roadways by which carts may obtain access, or even lines of railway as under the London Meat Market. It is generally desirable to avoid steps at the entrance to a market, but where a market is built on sloping ground, the entrances may be arranged on one side at the cellar or basement level, with flights of steps upwards to the market floor; and at the other side on the floor level, with flights of steps down to the cellars. Although cellars will, in most cases, prove profitable, there may be cases—as where meat and vegetables are brought in daily, and storage room has, therefore, little value—in which the construction of cellars might not produce revenue enough to defray their cost. Some of the cellar space may be utilised as cold chambers for the storage of imported frozen meat, or in warm climates for keeping at a low temperature meat killed in hot weather. There are examples of both these methods at the Smithfield Meat Market, the Riverside Fish Market, London, and at the Birmingham Fish Market. At the two latter, Artificial Ice is made at a cost of about 15*s.* per ton by the same apparatus that cools the air.

Market avenues should be spacious. **And continuous.** **Market gates.**

All the avenues of the market should be wide, and although much space, valuable for stalls, may apparently be thus occupied, the free circulation in the wide avenues renders them really remunerative. The exact dimensions depend somewhat on the size of the market and the nature of the commerce; but it is seldom that any passage between stalls should be less than 12 ft. wide, and the main avenues should be from 18 ft. to 25 ft. wide, and even wider if used as thoroughfares for vehicles. The perambulation of possible purchasers is much encouraged, and the business of the trader increased, by so connecting the avenues and galleries that passengers are not obliged to retrace their steps, but may pass on and away as they please. Stalls situated in a blind alley (*cul-de-sac*) are out of the stream of traffic, and lack custom. Where tolls are collected, it is necessary to hold command of the gates or doors by which goods can be brought in, but, subject to such exigencies, numerous points of entrance and exit are desirable.

Outside frontages.

The outside frontages of a market may be utilised if necessary by rows of stalls—connected or not with those within—facing outwards; the stalls projecting under pent or overhanging roofs. If the surrounding streets are valuable as business sites, the outside frontage of the market may be utilised for shops or offices, and a revenue obtained higher than that sacrificed in the space thus abstracted from within; but such a plan generally involves a departure from the principle of a public market, and sometimes obstructs the approaches. If the market be situated in the centre of a large open area which affords, outside the market, more space than is necessary for traffic, the available area may be paved and used as a wholesale market; and on the days when it is not so used, as a retail market for goods which will bear exposure. It is always desirable to have space outside the markets or in neighbouring streets as standing-room for carts, carriages, and horses. In choosing a design for a market (as for any public building), where highly ornamental or imposing elevations may be suggested, the suitability of such designs for the special site in question must be considered. It not unfrequently happens that designs seen to advantage on paper quite fail of effect when executed, if the market be surrounded by narrow streets or lofty houses which shut out the view.

Utilised for shops.

Open area outside a market.

Imposing designs sometimes fail of effect.

The material to be selected for market buildings of course depends largely on what is most easily obtainable in the locality. If masonry or brickwork can be executed well and at moderate cost, the walls may be built of stone or brick, and the architectural details of the façades and elevations designed accordingly. But iron is peculiarly suitable for market buildings; and even where brickwork or masonry can be obtained, such materials are often best confined to the foundations and dwarf walls on which iron columns stand. If the framework be thus entirely of iron, the spaces between the outer columns may be treated in various ways. Slightly-built brick walls with openings for light and ventilation may be placed to act merely as screens; or by placing only *grilles* or iron railings between the columns, the air may be freely admitted; this method, subject to the exigencies of climate, being often adopted in meat or cattle markets where ventilation is specially needed. In either case the light can be regulated by louvres (*persiennes*) of glass, wood, zinc, or iron; or by awnings or curtains. Tiles, slates, zinc, galvanised corrugated

Masonry or brickwork.

Iron buildings. *See page 860.*

Screen walls.

Ventilation.

Light.

Roofing materials. *See page* 870.

iron, and glass are the materials used for roof covering. In many countries where building materials have to be imported, tiles are found effective both in appearance and durability: they are made much lighter than formerly, and are easily fixed. Slates are serviceable in a climate like that of England, but they are fragile for export.

See pages 553 *&* 871. **GALVANISED IRON.**

Copper or zinc is the best metallic covering; galvanised iron, though cheap and effectual, not being very durable in cities unless periodically painted. The amount of glass must be determined not only by the light required, but by the exigencies of the climate. Instead of brickwork, iron panels, tiles, or terra-cotta can be used with good architectural effect; and in some cases, where the sides of the market are shaded from the direct rays of the sun, an iron framework is entirely filled in with glass.

Iron and glass.

Market stalls.

Uniformity desirable.

Stall fittings.

Although traders are certain to arrange their stalls according to individual choice—and too much minute detail should therefore be avoided in the design—it is desirable to maintain a general uniformity of appearance, and, by making the interior suitable for its purpose, avoid the necessity for unsightly additions afterwards. Thus the supporting columns should be provided with brackets, or with the means of attaching brackets at a uniform level; and if considerable weights have to be suspended—as at butchers' stalls—sufficient strength should be given to the various supporting parts. In warm climates, provision should be made for hanging curtains, or awnings; and large openings should be made at a suitable height in the walls to promote ventilation.

Hanging curtains provided for.

Cost of covered markets.

Calculated according to area. *See page* 879.

According to entire space enclosed.

As customary for dwelling-houses.

The cost of covered markets depends on their area and height, and the character of the design. In estimating the cost of such structures, the "square" (equal to 100 superficial feet) is generally adopted by English engineers as the unit of measurement; but as buildings may be erected to a great height, and it is obvious that then the expenditure for covering a certain superficial area will be increased, it might appear as if the cost would be more fairly measured according to the cubic space enclosed by the walls from the floor to the ridge of the roof, as is usual in stating the cost of ordinary buildings. Thus, in England, the cost of cottages will range from 5*d.* to 7*d.* per cubic foot, of villas from 8*d.* to 10*d.*, and of mansions from 1*s.* to 1*s.* 6*d.*; but it is because, in buildings of these kinds, the sizes of rooms, the numbers of doors, windows, and the other fittings which determine the expenses, bear a not very variable proportion to the space enclosed, that such moderate limits of difference will be found to embrace the cost of

Superficial area the best measure.

almost every kind of dwelling-house. But when public buildings of so variable a character as markets are designed, in which the interior numbers or weights of parts bear no fixed relation to the space enclosed, and when, moreover, buildings are made so high as to add greatly to the cubic space without adding proportionately to the cost, then any application for purposes of estimate of a fixed price per cubic foot will be found fallacious and misleading. It is impossible, therefore, to give any such standards of cost; and the superficial area becomes a safer measure if the qualifying circumstances be borne in mind. The height which is suitable depends largely on the climate and the nature of the commodities, both of which circumstances determine what amount of ventilation is necessary.

Preparation of site.

Levelling and draining.

Macadam paving.

See page 147.

Granite.

Asphalt.

Lighting and water-supply.

For the purpose of estimating the cost of markets, the preparation of the site may be separated from the erection of the building. If an open market-place only is to be formed on a site already clear, levelling and draining will probably cost from £2 to £4 per square. The kind and cost of paving of course depend upon the materials obtainable. An entirely new macadamised rolled surface on a suitable substratum would in England cost from £4 to £5 per square. Paving, with granite setts upon concrete, costs in England from £6 to £8 per square. Asphalt (of the modern kind used in street paving) on concrete forms a clean and durable flooring for a market-place; a thickness of 2 in. on 6 in. concrete costing from £6 to £9 per square. For the inside of a market where there is no traffic of vehicles, asphalt ¾ in. thick would suffice, at a cost of from £3 to £5 per square. The cost of electric or gas lamps and of supplying water would in most cases have to be added in estimating the cost of an open-air market.

Cost of sheds of simple design.

Strongly built unenclosed markets.

Cost of flooring.

Assuming average prices of material, iron sheds or arcades or bazaars of the simplest kind from 18 ft. to 25 ft. wide, open at the sides, and from 12 ft. to 20 ft. high, would cost from £8 to £14 per square; and similar buildings, enclosed at the sides with wall-screens of corrugated iron, and having roof-covering of iron and glass, would cost from £12 to £18 per square. Stronger buildings, as suitable for unenclosed markets in a large city, cost from £15 to £25 per square. The foregoing prices are exclusive of the preparations of the site, of flooring, of interior stalls or fittings, or of water and gas supply. A floor of concrete with a cement surface costs from £3 to £4 per square; wooden flooring on sleeper-walls and timber joists from £6 to £8 per square; wooden blocks bedded upon concrete,

Cost of enclosed markets. *See page* 880. IRON ROOFS & BUILDINGS.

Expensively-built markets.

London markets, examples of high cost.

Cost per "square." *See pages* 338 & 880.

from £7 to £10 per square. Enclosed markets strongly constructed of iron, with wall-screens of brickwork or brickwork combined with iron grilles, cost, including flooring and lighting, from £50 to £80 per square, and when lofty or imposing designs are carried out, the cost reaches £100, the exact price depending on the height of the structure and on the character of the design. It is obvious, however, that on a given area the possible range of expenditure is very wide, and it will be found that even the limits of cost above stated do not include markets of the most expensive kind. In London, for instance, where space is valuable, where a constant and enormous trade has to be carried on, and where, therefore, high rents can be paid, it becomes necessary and remunerative to construct buildings of the strongest kind, and to provide every adjunct for facilitating the commerce of the market. Moreover, in a capital city a certain architectural display is demanded, which adds to the cost. The more modern of the London markets have lofty and imposing elevations, strong walls of brickwork with ornamental masonry, massive iron gates, cellars, stalls enclosed as two-storied shops with staircases, offices, cranes and elaborate stall fittings. Including all these and the numerous other appurtenances of a public market, and everything but the purchase of land, the cost reaches £200 per square.

The management of markets. *See page* 24.

Free-trade.

Onerous conditions to be avoided.

Even after a suitable market has been erected on a well-chosen site, its success, both financially and in popular estimation, depends greatly on the management. The principle of a public market demands free-trade and competition; and care must be taken that the normal tendency of the traders to combine against the interests of the public is not in any way assisted or encouraged by the regulations. It is generally disadvantageous to farm out the tolls to one lessee, or to allow the stalls to be occupied by cliques or trade-unions, to the exclusion of the independent trader; or to make conditions too onerous for traders of small capital.

Bye-laws.

Regulations and prohibitions.

Bye-laws are necessary for the due management of a market: such laws having reference to the days and hours of business; the periods for which the pens or stalls will be let; prevention of overcrowding or other cruelty to animals; the tariff of tolls and the terms of holding; prohibition of obstruction in the avenues of the market; the price or conditions on which water or gas will be supplied; conditions as to cleanliness and the removal of refuse; the kind of commodities which may be sold, and limits, if need be, as to bulk or weight; the inspection of weights and measures; the preventing the sale or exposure of unwholesome provisions, or the undue storage of perishable food; the standing-places for horses or carriers' carts; the extinguishing of fires and light; the plying for hire of porters and others; the hawking and crying of goods for sale; and penalties for infringement of the bye-laws.

Penalties.

Over-management undesirable.

A market may, however, be over-managed, and if, by too strict regulations, the traders are hampered in their business or purchasers subjected to excessive control, there is a risk of the market becoming neglected. Sometimes such over-regulations arise from philanthropic motives, or from overstrained sanitary precautions, but they are none the less prejudicial to the success of the undertaking; and, within due limits, the rules should be framed as far as possible to accord with the habits and traditions of the people.

Judicious framing of rules.

Informations necessary for designing markets.

It will be evident from the wide range of costs given on page 339, that a full knowledge of the circumstances, of the class of buildings required, and of the funds available, is necessary to the proper designing of a market building; and for enabling capitalists, engineers, contractors, or municipal officers to estimate the cost and revenue of the undertaking. The information required may be summarised as follows:—

Map of town.

1. A *Map* of the town, with the principal streets, railway stations, existing markets and public buildings marked upon it, and showing the site chosen for the market.

Plan of site.

2. A *Plan* on an enlarged scale of the site of the market and the approaches to it; sections showing the levels of the site; and a description, with photographs, of the style and height of the buildings in the neighbourhood of the site.

Site described.

3. The *Condition of the Site*, such as whether it is cleared and levelled, or whether buildings or other obstructions have to be removed. The proprietary rights, if any, which exist with regard to the land, and the terms on which they are to be dealt with. The nature of the soil and its suitability for foundations, the drainage system which exists in the neighbourhood of the site, the sewers or drains (as indicated on a plan) to which the waste-water and the rain-water from the roofs must be conducted.

Rights affirmed.

Foundations and drainage.

Clearing of site.

4. If the new building is to occupy the site of an *Existing market*, the arrangement proposed for the removal of the old structure, and for temporary accommodation during the rebuilding.

The kind of trade to be carried on.

5. The *Service* for which the market is intended; whether for wholesale or retail trade; the nature of the commodities; and whether galleries or cellars are required.

Population. 6. The present *Population* of the town, its past rate of increase and the indication of increase for the future; the size, shape and **Existing markets described.** appearance of existing markets; the nature of the business transacted in them, and the rates of toll or rent; and the reasons which have suggested the necessity or advantage of the proposed new market.

Climate. *See page* 873. 7. The nature of the *Climate*, the frequency of rain, and the occurrence of heavy rainfalls or snow, the extreme variations of temperature, the direction of cooling winds, the force and direction of heavy winds or hurricanes, and such other particulars as may determine the mode of covering, lighting and ventilating the building, and the removal of rain-water.

Building materials. *See page* 74. 8. Particulars, as already described, concerning the *Materials* for building and the timber for staging which are obtainable in the town or which may be purchased in the country; the kind of workmen and the rates of wages; the facilities for landing and transporting **Dues and taxes.** materials; and particulars as to dues, taxes, and imposts.

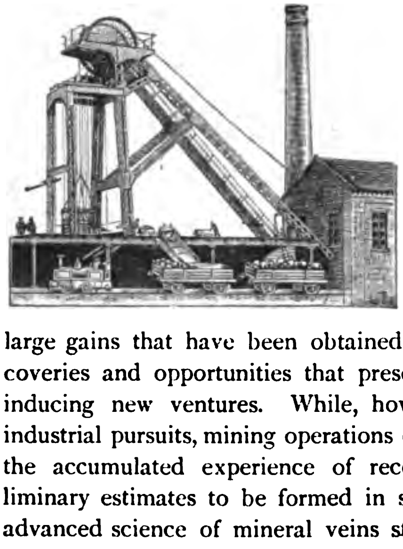
Water-supply. *See Chapter IX.* 9. The nature of the *Water-supply*, the contiguity of the main to the market, as indicated on the plan; or, if there be no water-works, the wells or other sources in the neighbourhood of the market, and **Mode of lighting.** *See pages* 235 *&* 254. the terms on which the water can be obtained; also the cost of gas or electric lighting.

Financial. 10. If assistance be asked in providing *Capital*, the nature of the concession to be granted by the municipality, or the terms on which the markets are to be established, should be described, together with the data upon which the calculations of revenue and profit have been based.

[*See also* CONCESSIONS: IRON BUILDINGS AND ROOFS.]

CHAPTER XV.

MINING ENTERPRISE: COAL, COPPER, GOLD, IRON, LEAD, SILVER, TIN, GEMS.



MINING stands apart from other undertakings in that it develops the natural resources of the earth, the minerals when obtained being a direct addition to the wealth of the country where they have lain dormant. Although mining is among the most uncertain and speculative of enterprises, the large gains that have been obtained in the past, and the new discoveries and opportunities that present themselves, are continually inducing new ventures. While, however, as compared with other industrial pursuits, mining operations offer the attractions of a lottery, the accumulated experience of recent years allows accurate preliminary estimates to be formed in some kinds of mining; and the advanced science of mineral veins still further tends to reduce the uncertainty that must ever attend on all mining ventures. It is not the purpose here to deal with details of mineralogy, but merely to draw attention to the leading circumstances which have to be considered in the inception of new mining projects.

Mining ventures speculative.

Science of mining reduces risk.

In almost all countries where mining is carried on, there are laws to encourage or control, and where such laws are wanting or are ill-administered, mining operations are hindered. The first and most important relate to the terms on which mining will be permitted, and the regulations concerning the tenure of land. There is in most countries a considerable departure from the ordinary laws concerning the ownership and occupation of land. This is the case even in England, where the rights of property are so well guarded. Examples

Mining laws.

Tenure of land.

of mining laws and customs are afforded by the local rules that have grown up from ancient times in Cornwall and Devonshire for tin and copper, and in Derbyshire for lead. **Customary laws.** Mining customary laws, as anachronisms incompatible with modern industrial conditions, are, however, likely to disappear. At present, however, they exist and have the force of law; indeed, many of them have been embodied and confirmed in special Acts of Parliament.

French mining law. Modern mining laws are of two types—those which, as in France, reserve an arbitrary discretion to the Government and hamper the miner with restrictions, **Spanish law.** and those which, as in Spain, determine all ordinary cases by fixed and simple rules, favouring and facilitating the "denunciation," working, and transfer of mines. In countries where the latter system is adopted and where numerous mining rights are acquired in the same district, confusion sometimes arises from the abundance of concessions, because they overlap. Therefore care should be taken to enter all mines in the public register of property, and to compare and investigate the title before purchasing or leasing. The text of modern mining laws is usually meagre, and the administrative regulations and practical rules that guide the Government officials are what chiefly interest the miner.

Basis of mining law. The general basis for mining laws, and of the customs referred to above, is the assumption that the discovery and working of mines are for the public advantage, and that if the owner or occupier of the land does not work the minerals, the right ought to be granted to whoever will undertake to do so. In some countries the minerals are held to belong to the State, independently of the ownership of the surface land, and in such cases the miner need make a bargain only with the State authority, which grants also, under certain reasonable restrictions, **Surface right.** *See page 346.* the right to take sufficient surface land on a fair rental from the owner or occupier. It is desirable also to secure from the landowner the right to use water, clay, sand, timber and other materials from the property, and to secure free access or right of way. **Rights and obligations.** Mining rights are generally qualified with the obligation to continue working under penalty of forfeiting the privilege.

Except where the mine is the absolute property of those who work it, **Rent or royalty.** some rent or royalty has to be paid for the mining rights and sometimes for way-leave also. In newly settled countries, where the land is not yet appropriated, a Government generally seeks to encourage mining by charging only a license fee, or small nominal sum sufficient to pay the expenses of Government surveys and supervision. Sometimes a Government will do more; will make surveys gratuitously or at less than cost, and will even in some cases assist in prospecting by lending boring-tools free or at small cost. A Government may do much to assist mining by making geological surveys and publishing such particulars as will assist in deciding upon new ventures. Mineralogical reports are as necessary to the progress of a country as are agricultural reports, but are not always so regarded. In many foreign countries monopolies are given or sold by the State for the working of mines, such concessions being sometimes accompanied by facilities, privileges, or guarantees.

Government surveys. *See page 26.*

Concessions. *See page 25.*

Rent may be paid in various ways, e.g. at a fixed annual rate, or per acre, or per ton of ore raised or sent away, or per ton of mineral extracted, or by a percentage of gross receipts, or by a percentage of net revenue. In some mining districts there is a reservation, varying from $\frac{1}{10}$th to $\frac{1}{24}$th, of dressed mineral, which, after inspection and valuation by the agent of the landlord, is taken by the miners who pay the value of this reserved portion, i.e. royalty. In the case of a joint-stock company the landlord may be paid in shares of the company for his rights, such shares being preferential, or equal or deferred, according to the prospects of success, the exact terms being arrived at as a matter of bargain. If the proprietor is certain of successful results, he will risk nothing in taking a deferred share in the earnings, and such an agreement encourages those who are providing working capital to run the risks of the enterprise. But the proprietor of the land will need to be assured of good management before agreeing to postpone his claim.

Royalty how paid.

In shares.

Deferred shares.

Fixed rents often prove onerous when the selling value of the mineral is low, or where for any reason the cost of production approaches the price obtained. Even when the royalty is charged at a rate per ton, a "dead-rent" or minimum is frequently exacted, which must be paid in any case, though it is merged in the rate per ton. If in any year the "dead-rent" exceeds what would have been due according to the tonnage, the lessee should be allowed to make up the deficiency in any succeeding year. As the dead-rent is supposed to be an incentive to the miner to work the mine and to safeguard the owner against neglect, so a like stimulus is afforded by the expenditure on plant which the lessee has to make and on which interest can only be earned by working the mine. As originally the landlord was only entitled to a portion of the ore actually raised, and minimum dead-rents are only a comparatively modern innovation, it is a

Fixed rents.

Dead rent. *See also page 354.*

question whether it would not be equitable to make provision in leases for reduction in dead-rent in proportion to the increase in expenditure on plant. Sometimes the lessee has the advantage of works already carried out by the owner or by a previous tenant, such as shafts, roads, buildings, or plant, and a royalty may include interest on such capital expenditure. In other cases these works are taken and paid for at a valuation. Besides the rent or royalty **Surface rent.** for the minerals, a rent is generally fixed for the surface land required, or which may be damaged either by the works or by the refuse minerals, and for the additional land taken up from time to time. In Yorkshire and other parts of England the surface rent is fixed at double the current agricultural rent, and a sum per acre is fixed which must be paid by the miner for any portion of the land which on ceasing working he does not restore to a fit state for agriculture. The "pit hills" of refuse from a mine, although of small account where land is available for nothing, are often a serious expense. In **Short leases.** *See* ELBA, *page* 382. some countries the State grants short leases and relets the mines at regular intervals to the highest bidder, but in such cases the fixed plant is included in the property.

If a mine be sold, the price may be deemed the capitalised value of the rent or royalty, taking into account the risks and probabilities **Purchase of mines.** for the future. To the seller there is the advantage of realising at once. To the purchaser there must be the advantage of buying for a much lower sum than the rent or royalty would amount to on the anticipated output. A prudent purchaser endeavours to combine the advantages of both plans—to commence with a rent or royalty till **Option of purchase.** the mine is thoroughly proved, reserving the option for a given period of buying the mine at a price fixed in the lease. If a purchaser or lessee is proving the mine at his own cost, he obviously requires a large prospective or speculative profit to induce him to run the risk. The temptation to work mines recklessly, dangerously, or without regard to the future for the sake of an immediately profitable result **Poor man mining.** (commonly known as "poor man mining") is, however, in many cases to be specially guarded against by the lessor or owner of the royalty. The farming of mines to contractors, or the letting on tribute by which the miners undertake to get the ore at so much per ton, though an equitable and convenient plan, may be injurious to the mine unless carefully supervised.

The existence of the mineral in remunerative quantities is one of **Proving of mines.** the first circumstances to be considered or proved, and it is mainly to the doubt which may exist on this point that mining ventures owe their speculative character. The uncertainty may be minimised by taking advantage of existing information and by full preliminary investigation. Although the presence of minerals in sufficient quantity can seldom be predicted with certainty, the negative may be often positively declared, and money has frequently been wasted in explorations, plant and otherwise, which would have been saved by a rudimentary geological knowledge or by making proper deductions from the previous investigations of others.

Negative certainty.

Prospecting.

In some cases the presence of the minerals may be obvious, and a practical miner accustomed to the country and the same character of mine can estimate the cost of extracting the mineral. In other cases, the employment of a trained mining engineer may be the condition on which alone a trustworthy report can be obtained. Such a person can ascertain and state intelligibly how much or how little information can be obtained regarding the mine. There are cases in which a prospector who is merely a geologist or mineralogist, or a civil engineer, mining foreman, or a mine accountant, cannot serve efficiently as a substitute for a mining engineer. A qualified expert may be able to detect at first sight a worthless or spurious mine, but he can rarely, without taking time to thoroughly examine and test the workings, speak positively regarding the prospects of a mine even if already worked; and in the case of new and virgin deposits he will usually require to make exploratory trials occupying a considerable time. In most civilised and settled countries mining enterprise is facilitated by official records or geological investigations which have been made or gathered together by the State or by scientific associations, and such records should be carefully examined before commencing operations which they might assist, or forbid.

Mining experts.

Geological knowledge.

Official records.

Surface indications.

See GOLD, *page* 377.
TIN, *page* 398.
LEAD, *page* 388.

The presence of minerals may often be surmised from outcrops and other surface indications, but though these seldom afford more than presumptive evidence, they may be quite sufficient to justify further investigations. There may be the actual presence of ore on the surface, either revealed by the weathering action of cold and heat, or where it has been washed bare of alluvial soil covering the bulk of the deposit. Other indications are, for instance, the presence of the mineral in the sand or mud of a river bed, the impregnation of water with metallic salts, or the presence of minerals known elsewhere to be associated with the special mineral sought. In some cases the ore may have been brought down by streams from higher ground, whither the sources should be traced. Metals which occur in a state of approximate purity are said to be "native." Such metals are seldom so found in veins, the non-metallic portion of the ore being known as matrix, gangue, reef or veinstone.

Metals found native. *See pages* 364, 370 & 392.

River gullies and their small lateral feeders are the most promising lines for exploration. Too much reliance must not, however, be placed on surface indications. Thus while water on analysis may be found to contain certain sulphates of copper or iron, the ore is very frequently so diffused through the strata as not to pay the expense of getting it. The most careful examination of the surface often fails to give satisfactory information, and boring or excavation becomes necessary. Sometimes mere trenches or pits are sufficient to reveal the ore, but in other cases very deep borings may be required. Mineralogical knowledge or information concerning the results of neighbouring operations or other local circumstances may, as the boring proceeds, be a trustworthy guide as to the expediency of proceeding further. The modern use of the diamond drill and other improved boring apparatus affords great facilities for prospecting at a less cost than formerly.

Trial borings. *See* TOOLS, *pages* 406 & 813.

Diamond drill. *See page* 892.

Chemical knowledge required.

Even a moderate knowledge of chemistry and assaying processes is of great assistance to an explorer, for though it would not be safe to base extensive operations on any but complete analysis by an expert, yet there are often cases where sufficient proof for the immediate purpose may be obtained by less experienced persons. To assay correctly requires a course of special training, but the simpler experiments with the blowpipe and by chemical tests prove the presence of the minerals, and will generally afford results sufficient to determine the expediency of procuring more elaborate and precise assays.

Preliminary assays.

Old workings.

In most countries, old workings or traces of old trials are the most important practical indications. In many districts in Europe and the East, most of the surface indications have been detected and examined in ancient times, and the important question in such cases is the cause of abandonment. This may be due to such events as war, revolution, or conquest by a barbarous race; to the exhaustion of a superficial rich ore, such as soft hematite, or copper and lead carbonates; or the inadequacy of the mining appliances employed to cope with the difficulties of deep working. Very often mines were worked down to the water level, means for pumping the water being wanting. Steel drills, explosives, good pumping machinery, improved means

Causes of abandonment.

Improved methods available.

of transport, metallurgical treatment on the spot, or the discovered value of by-products formerly valueless, may enable the modern miner to derive profit from works that were necessarily abandoned. Old workings sometimes disclose that failure has resulted from mere ignorance of underground surveying, and in other cases the débris on the mine bank may show that unskilled smelting experiments brought inevitable failure.

Verification of proofs.

Even when the existence of the mineral has been ascertained by preliminary investigations, it is expedient to prove it further before large sums are expended either in purchasing the mineral rights or in expensive plant. Leaving cases of actual fraud or misrepresentation out of the question, a large proportion of the disappointments and losses from mining ventures have arisen from basing large expenditure on insufficient facts. Prospecting in advance should proceed step by step with the tentative working. Even where the circumstances are such as to make it evident that operations on a large scale will be the best or only plan to obtain satisfactory results, practical working on a moderate scale may be first attempted. This, if successful, even though not remunerative, may justify the larger expenditure; while if unsuccessful, such a mode of procedure will have minimised the loss.

Preliminary risks.

In the preliminary investigation of a mine there are two distinct risks to be encountered; first that the costs of investigation will be more than anticipated, and secondly, that when proved, the results may show that the working of the mine will be unremunerative. The first risk may be avoided by making a separate bargain with those accustomed to such work, to excavate to a given depth in one or more places, or to investigate in some other prescribed manner the condition and richness of the mine. Even after allowing a profit to those who do this preliminary work, the cost will generally be less than to those who have to find plant and supervision for their one operation; and very often the contractors will undertake the work at what they estimate as the bare cost, or less than cost, to themselves if a share of the profit is assured to them in case of success. By this means, much of the trouble and expense of machinery and organisation may be saved till the actual development of the mine is resolved on. The restriction of the preliminary expenditure to an agreed sum also affords a convenient means for dividing the outlay between those who have varied interests in the property.

Cost of proving mines.

Separate contract for proving.

The value of exploratory work will almost wholly depend on its

Choice of miners for trial work.

being adapted to the particular inquiry. A mining captain admirably fitted to direct the daily work of a mine on a system to which he has been accustomed is not necessarily qualified to prospect in a different country under different circumstances. At this preliminary stage, the services of a practised geologist with little mining knowledge may be preferable to those of an average mining captain.

Proving before purchase.

The success of mining ventures depends, it will be seen, on so many circumstances besides the mere obtaining of the minerals, that in the purchase or renting of a mine it is seldom that an absolute payment can be prudently made to the vendor, or long engagement as to dead-rent be entered into, till full proof beyond mere preliminary success is obtained. Some equitable plan should be arranged by which payment is made contingent on profitable results, or is made secondary to the preferential profits of those who are embarking capital in the enterprise. On the other hand, it is a fair subject for speculation if a mine is offered for actual sale at a low sum because the results are still doubtful.

Payment by results.

Bulk differs from sample.

Disappointment often arises in finding that the produce of a mine does not accord with the previous analysis of samples. If this discrepancy become apparent after the separation or smelting of the metal, it may not be due either to errors in the sampling or assaying, but only to the circumstance that large quantities of ore can seldom be treated so exhaustively as small quantities in a laboratory. But if it is the ore itself which shows the difference, it will probably be owing to errors in sampling rather than in assaying. There is no difficulty in obtaining the services of skilled and trustworthy assayers, who will correctly report on what is put before them. But sufficient pains may not have been taken to ensure the employment of a skilled and trustworthy sampler. To take from the workings of a mine, or from the heap of ore on the bank, or from a cargo of 500 tons, such a portion of the ore as will when further reduced to a sample of 5 lb. correctly represent the whole, requires not only honesty and care, but skill, only acquired by practice.

Assays.

Sampling requires skill.

See pages 426 & 438.

Estimate of cost and profit.

Having proved that minerals are to be obtained in apparently paying quantities, and having arranged the terms of purchase or tenure, with proper conditions as to access and transport, the profits will, thirdly, depend upon the accuracy of the estimates of the cost of getting the mineral, and its value when got. There may be abundant mineral of good quality and a ready market for it when obtained, but there may be an insufficient or no margin between the cost of getting and delivering to market, and the selling price.

Expenditure subdivided.

The cost of getting and bringing to market may be divided into four main items; *First*, the current expenses of labour, superintendence, materials and stores; *Second*, the cost of transport; *Third*, the royalty or tribute; *Fourth*, the interest on the capital sunk in purchasing the mine and plant, and on the liquid or working capital. The first two items must be paid in full; the last two may admit of alteration. In estimating the first of these items—the cost of getting—it is seldom that precedents sufficiently identical are available. Even in the same district the depth may be greater than in a neighbouring mine, and more waste or overburden have to be removed; or, owing to the nature of the strata, the labour of sinking may be tenfold that in a previous case. Excessive water or other difficulties may be encountered which upset all previous calculations, while, in a new country or district, the whole circumstances may be so different from the previous experience of those concerned as to render their estimates fallacious. The various methods of approaching minerals, such as by drifts, levels or vertical shafts and galleries, or by open-cast, have each advantages in particular cases. But each system has its drawbacks, all of which must be taken into account in making estimates of cost and profit. There is not only the cost of bringing to bank, but the cost of dressing or separating the ore from the gangue or otherwise preparing it, if such operations be needed at the mine. Some ores are more refractory than others; elaborate machinery may unexpectedly be needed; labour, water, fuel, timber, or other necessaries may be scarce; or the skilled management essential to success may be wanting. Water is necessary in almost all mining operations, as well for dressing the ore as for steam boilers, and, where fuel is scarce, water power is the only alternative. The rich gold mines of the Transvaal would have been practically worthless had it not been for the abundant coal available. Where there appears to be insufficient or no margin between outlay and return, an investigation of the methods adopted by others may show the possibility of saving. While modes of working which have proved successful with certain kinds of ore, or with high selling prices may under less favourable circumstances prove unremunerative, it does not follow that further working will not pay under improved management.

Getting and raising.

Contingencies.

Choice of methods.

Water and fuel.

TRANSVAAL GOLD. *See page* 378.

Improved methods.

In this matter of estimates of probable cost of winning and

Misleading precedents.

See COPPER, *page* 366.

dressing ore, the man who judges only by particular local precedent is at a special disadvantage. An engineer of wider knowledge will apply the principles of ore winning and ore dressing to the particular rocks and minerals of the mine. The improvements due to scientific methods of winning ore are inestimable. The cost of getting and dressing ore in some of the chief European and American mines has been reduced by nearly one-half under the direction of competent and painstaking mining engineers.

Transport.

See also pages 379 *&* 467.

Tolls.

Roads and canals.

Way-leaves.

Places of shipment.

Transport is an element in the economy of mining the importance of which depends mainly on the proportion of weight to value in the minerals. Even where the means of transport appear to be close at hand, it is necessary to confirm or acquire facilities or rights of way from the mine to the line of route, and if possible, free from toll. While the exploitation of mines is generally left to private enterprise, it is the proper function of the State or local authority to make or promote the making of roads, railways, or canals, so as to develop the mineral riches of the country. Royalty or rent for "way-leave" is sometimes charged by the owners of neighbouring lands or mines, over, under, or through which the minerals may have to be carried. Rich mines have often been commercially valueless for want of cheap transport; and as the construction of a road, railway, or canal, or the improvement of a harbour or place of shipment has been the essential condition for developing the mine, the first profits are due rather to those who incur the risk and expense of creating such facilities than to those who are the owners of the otherwise inaccessible mineral. But if the enterprises are kept separate; if a certain amount of traffic be guaranteed by those who work the mines, then the risk is incurred only by the guarantors, who need only ensure a revenue to pay interest on the fair cost of the road without giving up any of their speculative profit.

Water carriage.

Ore and fuel brought together.

Water carriage is, where available, the cheapest for the conveyance of minerals, and next in cheapness comes railway carriage, and it is to her advantage in these respects, as much as to her mineral riches, that Great Britain has owed her industrial pre-eminence. The facilities for transport often determine the treatment of the ore at the mine. It may sometimes appear best to bring the mineral to places more or less distant, where fuel, water, labour and other necessaries are cheapest for dressing or smelting; but this depends greatly on whether the mine be situated on elevated ground. If it be so, the mineral may by its own gravity afford the means of movement.

Where this is not the case, it may be expedient even at great expense in these respects to treat or partially treat the ore at the mine so as to reduce the weight that has to be carried. Copper, lead and silver afford examples of minerals usually concentrated at the mine because of the exigencies of transport.

Ore treated at the mines.
See COPPER, *page* 366, LEAD, *page* 389, SILVER, *page* 394.

Where situated on the sea or on navigable rivers, ore can often be carried 3000 miles more cheaply than 50 miles by road, and mines so situated have a value accordingly. Coal is carried from Pittsburg to New Orleans, 1500 miles by river, for less than 2*s.* per ton; iron ore is carried across the Atlantic for 10*s.*, while in the absence of railways 6*d.* per mile is not an excessive charge for land carriage. Sometimes ore is carried by sea at very low rates of freight, or even without charge, because of its utility as ballast, and mines may depend entirely for their success, which may thus be only temporary, on such facilities.

Cheap transport.

Ore carried as ballast.
See pages 379 *&* 445.

As incident to the total cost of transport, the arrangements for shipment must be considered. Even when the ore is contiguous to the river or sea, or after it has been transported thither, there are often difficulties in the way of putting the mineral on board ship. Expensive piers or jetties may have to be constructed, cranes erected, boats, barges and other apparatus of shipment provided. Sometimes there are difficulties which hinder the approach of vessels, such as bad anchorage ground, insufficient depth of water, want of harbour accommodation or of shelter from storms or winds. Thus the profit of mining operations may depend upon the construction of a breakwater or pier rather than on the actual operations at the mine. But even when all these difficulties have been met, the rates of freight will depend largely on the chances of reciprocal trade, for shipowners prefer to send their vessels to places where there is cargo to be carried both ways. Sometimes the ship or railway that brings the ore to the fuel, may carry back fuel to the ore, and smelting operations be conducted at both places. Thus iron ore from Bilbao and coal or coke from Middlesbrough are interchanged, copper ore and coke between Spain and England, and iron, coal and coke between Northamptonshire, Derbyshire, and Yorkshire. The treatment of copper ore by the wet process also affords such return cargo in the scrap or pig iron necessary for precipitation.

Places of Shipment.

Piers and cranes.
See pages 128 *&* 787.

Rates of freight.

Ore and fuel interchanged.
See page 368.

From what has been said, it will be seen that in considering the facilities of transport, every step from the mine to the place of consumption must be held in view before a comparison of one mine with another can be made, or a correct estimate of profit and loss be arrived at.

Rent and royalty.

Dead-rent. *See page* 345.

Surrender of lease.

In exercising mining rights as referred to on page 344, it is of course necessary, if rent, royalty, or tribute in any shape has to be paid, that there be a margin between the cost of getting the mineral, including transport, and the selling price to allow the paying of such a charge. It is obvious that the actual current expenses of getting and transporting the ore must be paid, and what remains over forms the profit to those concerned. It may sometimes, therefore, become necessary to reconsider the rates of royalty, and those who are entitled to it must elect between a cessation of their rent or the acceptance of a less amount. If a dead-rent be payable, then the whole capital and plant of the miners is generally answerable for it, although sometimes in mining leases provision is made for a surrender of the lease on moderate terms if further working appear unprofitable. It is for this reason that payment by a share of profit rather than at a fixed rate is the most equitable for all concerned. There should also be a reserve or provision for the fulfilment of the contract by the lessee, and surrender in good condition at the end of the term.

Interest on capital.

Deterioration of plant. *See page* 770.

Sinking fund. *See pages* 39 *&* 359.

The wasting value of mines.

Interest on capital is a charge on mining operations that varies according to circumstances, but it is an incident of most mining ventures that capital once sunk cannot be recovered. Therefore, if the earnings are insufficient after payment of current expenses to pay the expected or stipulated interest, the investor has to be content with a smaller rate as better than none at all, for if the mine stops working he cannot transfer his capital elsewhere. If, owing to low prices, or for other special reasons, it is expected that profits are only temporarily diminished, it is generally expedient to continue working; but care should be taken to provide for the maintenance of machinery and plant, even at the expense of stopping interest and dividends altogether, so that it may not be found when prices improve that the machinery is worn out, and a fresh capital expenditure is needed to reinstate the works. But if it be found that the mine approaches exhaustion or the lease be coming to an end, the establishment of a sinking fund becomes necessary. Mines are examples of undertakings which by their very nature have only a transient or wasting value, and in which, therefore, if the capital of the concern is to be preserved intact, everything that will be irrecoverable when the mine is exhausted or abandoned should be gradually written off out of revenue. Although if established at the commencement, a small annual investment or sinking fund will accumulate rapidly in a term of years, such a symmetrical arrangement is seldom carried out, shareholders generally preferring to divide profits to the fullest extent, without making provision for those who are to follow them.

See COLLIERIES, *page* 359.

The profit or loss of mining operations obviously depends upon the relation which the expenses of obtaining and transporting the mineral bear to the selling price. Gold as the ultimate universal standard of value is the only metal that does not fluctuate in price, except indirectly by the rise and fall in the price of commodities, and if the cost of getting and treating gold can be assured within moderate limits of variation, the results are certain. But with all other minerals there are not only the risks incident to the mining and treatment of the ore, but also those of fluctuating market values. Sometimes, as in the case of coal and iron, where transport forms a large proportion of the total expense, the available market may be limited to a certain geographical area, and the selling prices may depend entirely on the local demand and supply, and may be effected only indirectly and to a moderate extent by the prices in other countries. Even in the case of the more valuable minerals, import duties may protect the miners from the competition of other countries. Indeed, mines are sometimes opened out and worked at a cost which it is known from the commencement would be unprofitable except thus protected. But generally in the richer metals, such as silver, copper, tin or lead, the selling price at any particular time depends on the current prices in the great markets of the world, and mines successful in all other respects may fail because of the depreciation in values from causes quite beyond the control of those affected. As there must be a continuous increase in the demand for most metals, a depreciation in values when it occurs is mainly due to the discovery and development of new mines.

Selling price of mineral.

See page 370.

Fluctuating values.

Protective tariffs.

See COPPER AND LEAD, *pages* 369 & 392.

Excessive output.

Sometimes an increased supply is due to the discovery of minerals in situations and under conditions which allow of cheaper working than elsewhere, and also to the invention of processes which reduce the cost of treatment, or which allow the working of ores too poor for previous methods, or which have been thrown aside as the waste products of some other kind of treatment. On the other hand, while the cost of getting and treating the mineral may remain the same, the discovery of some use for by-products so increases the total net returns as to allow the chief or staple product to be sold at a lower

Causes of increased supply.

By-products.

rate than formerly. Those mines in which the mineral does not contain these by-products, or where the skill or machinery for obtaining them is wanting, or where there is no use or market for them if obtained, cannot compete on equal terms with mines more favourably situated in these respects. The fall in the value of lead owing to the development of silver-lead mines, where the lead is a secondary or by-product, is an example.

See page 392.

Storage of minerals.

When a time of intense competition arises, the working of a mine will generally be continued so long as there is a balance of profit, however small, and it may even be expedient to continue working at a slight loss, if an improvement in price is expected, rather than incur the greater loss and deterioration which would result from a stoppage. A reserve of working capital then proves useful, as the mineral may be stored till prices improve, and such a reserve would be provided by the depreciation or sinking fund suggested on the preceding page.

Cheap native labour.

Mines may pay native workers who are content with small earnings, and yet be entirely unremunerative if worked on a large scale with large capital expenditure and costly superintendence. On the other hand, mines may afford profit only when worked on a large scale with expensive plant and organisation. Profitable working often then depends on the workable area of the deposits and the number of men who can be employed; and these circumstances should be considered with reference to wide and thin veins, pockets and other formations. Coal, iron and pyrites mines can seldom be worked profitably except on a large scale. Thin veins of cobalt, argentiferous copper and argentiferous lead may often be very cheaply worked.

Joint stock mining.

It is seldom that any but very small mines are worked by private persons or firms, some form of joint-stock combination being generally deemed preferable by those who invest the capital, the speculative nature of mining rendering a limitation of risk desirable. The amount of share capital is from the outset a matter of importance. Too often the nominal capital is unduly large, so that earnings which would be remunerative in paying interest on the real costs of development and working are quite insufficient when spread over the fictitious value assumed for the purposes of promotion. It is desirable to maintain the issued capital as nearly as possible at the amount actually expended on the operations; to call up more capital only as wanted for working, and to let the profits of those

Excessive capital.

who have any other claim on the undertaking come after a fair return has been made to those who have actually expended money on it. Even where an increase of capital consists in large measure in "deferred" shares, these are often a cause of difficulty unless the control is in the hands of the real capitalists, for in the desire to show profits large enough to reach such deferred shares, insufficient provision may be made for wear and tear of plant or for liabilities not immediately apparent, so that thereafter more capital may have to be called up for renewals or for other obligations properly chargeable to current earnings. The abuses which have led to the ruin of many mining ventures might be averted if a regular audit of the accounts and reports were made by an experienced and independent mining engineer. The adoption of this precaution would probably reveal the causes of much superfluous expense. Directors who are not experts cannot be expected to appreciate the wide differences which exist in the design and construction of mechanical appliances, or to recognise the true value of returns and accounts concerning highly technical matters. In some countries a regularly qualified mining accountant or other expert is a necessary adjunct to a mining board. In those countries the common excuse that the directors have been misled through ignorance of technical matters is consequently inadmissible when mines have failed through mismanagement or fraud.

Deferred shares.

Audit of accounts.

Mining accountants.

Some mines are worked under what is known as the "cost book" system, by which the adventurers or group of persons who are working the mine, instead of subscribing at the outset capital sufficient for the total estimated expenditure, meet from time to time to examine the accounts of expenditure and receipts, and then decide either to stop further outlay or to proceed and pay up more money or divide the accrued profit. This system is nominally "unlimited," but is really controlled by the associates, a partner who does not wish to contribute further, having the alternative of surrendering his share. But unless the accounts are on each occasion brought really up to date, and all assets and liabilities clearly stated, there is as much room for mistake as with an ordinary "limited liability" company; and indeed experience goes to show that the risks of mining are greater by such a system.

Cost book system.

COAL is intrinsically the most valuable of all minerals, for it is not only necessary to the reduction of metals, but, as the chief and indeed

Coal mining.

the only staple fuel, it is, as potential heat force, one of the three sources of energy which are the only substitutes for animal power, the other two being wind-force and the gravity-force of water. The mining of coal may be deemed profitable wherever it can be obtained of such a quality and at such a cost as to compete in supplying an existing demand with coal obtained from other sources, or with other kinds of fuel. In these cases the risk of mining would lie in the fall of price below the cost of production, or inadequacy of the demand when the additional supply became available. The creation of a new demand or the indirect advantages that may be expected from the development of new coal mines, such as the smelting of minerals, useless till the fuel is obtained, or the cheapening of railway working and of steam navigation, are in anticipation speculative, and do not always repay within a reasonable time those who have embarked capital in the coal-mining venture. In such cases those are most likely to gain who have a share in both profits, that is, who will benefit by a cheap supply of coal as well as in the anticipated profits of coal-mining.

Where profitable.

Indirect gains.

Prospecting for coal.

In prospecting for coal, those countries or districts which geologically are formed of rocks older than the coal-bearing age may be altogether excluded from the search. The carboniferous system, which includes the coal-bearing rocks, is well known to geologists, but the strata of the system—sandstone, limestone, shale, and coal—do not lie in any regular order, and even where abundant coal has been found in a certain district, the various strata are subject to so many faults and irregularities, as sometimes to render inferences as to the existence of profitable seams of coal in the immediate neighbourhood uncertain. Coal, where it occurs, is generally found in numerous seams varying in position, thickness, and quality, and these, among other circumstances, determine whether the coal can be mined to advantage. Where coal is abundant, as in Great Britain, seams less than 20 inches thick do not repay the cost of getting, unless the quality be of a special kind, or unless iron, fire-clay, or other minerals can be obtained from the same workings. But in countries where thinner seams are found near the surface, or where the competing supply is burdened by the cost of carriage or other expenses, the coal may repay the cost of getting.

Uncertain inferences.

Thin seams.

Limits of depth.

There is no precise limit of depth within which coal may be found, or within which it can be mined to advantage. In Great Britain coal is worked to depths as great as 2500 feet, and in one

Heat in deep mines.

case nearly to 3000 feet, and, where there are in other respects no prohibitory difficulties shafts could be sunk and the coal won at greater depths. There are reasons for supposing that coal measures exist where they have never yet been reached. The great heat in deep workings is an impediment, but with modern systems of ventilation and by working short shifts much of the difficulty may be overcome. Approximately the heat increases 1° Fahr. for every 70 feet of depth.

Outlay for shafts.

Repaid by area worked.

Expenditure in large collieries.

Underground roads.

Railway sidings.

The return from a given outlay depends greatly as in other mining operations on the area of mineral which can be developed from one central system of shafts and machinery, and where the seams are at a considerable depth, large capital expenditure may be essential to success, although the amount of pumping does not increase with the depth. Generally, indeed, the deeper the pit the drier it is. Where coal lies near the surface, a pair of shafts may be sunk for the mining of only a few acres of coal; but in the case of deep shafts a thousand acres may have to be worked from one pair of shafts in order to justify the first outlay. For in modern collieries where economy is sought by a large daily output, there are heavy capital expenses beyond the mere development of the workings. Houses for workmen and extensive workshops may have to be built, railway wagons purchased, and other subsidiary expenses incurred. To bring to the surface and despatch 2000 or 3000 tons of coal a day, the disposition of the underground roads to allow of this output, the plant for the speedy loading of the cages, as well as the arrangement of railways on the surface for the marshalling and loading up of wagons, can only be effected by a large expenditure almost wholly irrecoverable when the colliery ceases working.

Capital irrecoverable.

Sinking fund.
See pages 39 *&* 355.

If £100,000 to £200,000 be expended on works and plant in the opening out of a new coalfield, not only must the profit income provide a remunerative rate of interest on such an outlay, but should provide for the re-imbursement of the capital at the end of the term. Where the mining of a large area can be divided over a long term of years, the setting aside annually of a very small part of the profits of working will enable a sinking fund to be established.

Trial borings.

See page 823.

The labour, expense, and risk of prospecting for coal depend mainly on the depth to which the trial borings must be made. Improved boring tools of various kinds, including the diamond drill, have greatly facilitated the making of trial borings and the sampling of the various strata pierced, and have reduced the uncertainty as to the cost of proving the ground to a certain depth. The easiest cases are of course those where the presence of coal is well known, where it crops out from the surface or has been already found at moderate depths, and its value confirmed by the successful working of neighbouring collieries. In these cases it is only necessary to ascertain that the coal extends over a sufficient area and is of good quality, and then to regard the secondary points, such as the terms on which permission to work the coal may be obtained, the means of transport, and whether a demand exists or may be created for the coal when won. In Great Britain a royalty ranging from 3*d.* to 8*d.* per ton, and in a few cases as high as 12*d.* per ton, has generally to be paid by those who mine the coal; but occasionally the rates are still higher, where the lessee has the advantage of previous expenditure on roads, shafts, buildings or plant; or where, because of the locality or quality of the coal, there are peculiar advantages. A royalty, or rent, as high as 2*s.* 6*d.* has sometimes been paid under such favourable conditions. Where considerable dead-rents are imposed, the burden of them presses severely on the lessee, and in Great Britain sometimes causes collieries to be worked to their full capacity in times of depression when the coal is not really wanted, in order to pay the rent, and so the depression is intensified.

Certainty of finding coal.

Royalty. *See page* 315.

Excessive dead-rent.

In some of the important coalfields of the world, though not in England, the coal can be got and brought to the surface at a cost of less than 3*s.* per ton, so that if capital be available the probabilities of success depend on the other points mentioned above. The cost at a shipping port of the best Welsh coal ranged, during the thirty years ending 1896, from 7*s.* 6*d.* to 18*s.* per ton, and of Newcastle coal from 8*s.* to 16*s.* per ton, the actual prices of both kinds having generally been between 9*s.* and 12*s.* The cost of sea freight has been low enough to allow the coal to be carried to distant countries, and sold more cheaply than coal from nearer sources, or even than contiguous coal where there are difficulties of transport. But the construction of railways, the improvement of navigable rivers, and other means of transport, are in many countries entirely altering the conditions of the coal trade; and in Japan, India, and Australia, the native coal is rapidly superseding the imported coal in the neighbouring countries within reach of the new supply; and the same change will eventually take place in South Africa when the coal deposits are further developed. On the eastern coast of the American continent

Selling prices of coal. *See also page* 530.

Coal in foreign countries.

the coalfields of Virginia and Alabama had in 1895 already begun to compete with British coal, and the Panama Canal or Nicaragua Canal will, if ever finished, admit the American coal to the western coast. But cheap sea transport does not depend merely on distance, but also on return freights, and in this respect Great Britain, which freely imports foreign products, has an advantage. The coalfields of China are equalled in extent only by those of the United States, and in a more distant future will have equal effect on the commerce and manufactures of the world. Coal from Japan and Formosa is already exported to the Chinese mainland.

American coal.

In the mining of coal there are circumstances which differ from those usual in the mining for other minerals. There are advantages and drawbacks attending the opening out of drifts from the sides of hills as compared with vertical shafts from which in each seam the galleries radiate, but it is seldom that mines can be developed to their full extent without vertical shafts. Trial borings are necessary not only to the mere finding of coal, but the opening and laying-out of a colliery can seldom be undertaken with advantage without preliminary examination of the character of the strata so as to ascertain the number and nature of the seams, and how they can be best approached and developed. Colliery shafts are generally larger and more expensive than for other minerals, one shaft having to serve for several seams and for the passage of a larger quantity of coal and waste than is required for the more valuable minerals. Circular shafts of from 12 to 15 feet diameter have been usual in England, but where an output of 2000 tons or upwards per day from a considerable depth has to be provided for, larger shafts of from 18 to 20 feet diameter are sometimes made. Such shafts have to allow for the double framing of the ascending or descending cages, and for the pipes and accessories of the pumps.

Drift mining.

Number of seams.

One shaft serves for various seams.

Owing to the variety of the strata through which colliery shafts have to pass, and to their depth also, water is almost always encountered, frequently rendering the lining or "tubbing" of the shafts necessary, as well as pumping machinery. The gases emanating from the coal, and released during the getting of it, as well as the fine coal dust which is so inflammable, also render necessary more elaborate precautions for ventilation than in the case of other minerals. In Great Britain the laws enacted for the safety and in the interests of the miners enhance the cost of getting coal. Such laws are those which require duplicate shafts, mechanical safeguards, and special

Explosive gas.
See also page 531.

Ventilation.

See page 2.

Truck system.

systems of ventilation, restrictions as to the labour of women and children, and prohibition of the truck system, which in many countries adds greatly to the gains of the mine owners.

Specific gravity of coal.
See also page 533.

Weight per acre.

Pit timber.

See page 2.

Labour-saving processes.

Electric transmissions.
See page 509.

See page 606.

Coal varies in specific gravity from 1·25 to 1·33, or in other words is $1\frac{1}{4}$ to $1\frac{1}{3}$ times as heavy as an equal bulk of water. The weight in proportion to its bulk is sometimes a matter of consequence in the shipment and stowage of coal. A cubic yard of coal weighs from 2100 lbs. to 2300 lbs., and coal may be reckoned roughly as weighing one ton per yard. A seam one yard thick will contain 4840 tons per acre, or 3,097,600 tons per square mile. As, however, coal seams are more or less broken up by faults, and a greater or less quantity must be sacrificed to the necessities of mining, the above quantities cannot be reckoned on. Thus there are the pillars of coal that must be left to sustain the roof of the workings, though in this respect much depends on the kind and cost of timber available for the same purpose. In Great Britain oak and larch are used for mine props, and there is a considerable importation of pit timber from Scandinavia. Steel joists are sometimes utilised for this purpose. Barriers or walls of coal are often necessary for ventilating purposes between different workings, or between different properties, for preventing the influx of water, and there is the very considerable waste of small coal in the getting, and the low price obtained for the small coal when sold. For these various reasons only from two-thirds to four-fifths of the nominal quantity can be reckoned on as a net product. The increased wages of colliers and the restrictions of the Mines Regulation Act have in Great Britain greatly stimulated the invention of labour-saving processes. Machine drills and cutting tools have reduced the cost of getting, and by deep under-cutting coal may be removed with less use of explosives than formerly. The transmission by electricity of power generated on the surface has been introduced with great advantage for the hauling of wagons, pumping, coal-cutting and other operations. Oil engines are also successfully applied to these purposes, where electricity is not conveniently available, and where the power needed does not exceed 10 horse-power.

Deduction for waste.

The cost of transporting coal may be divided into two main items, the interest on the capital expenditure for providing means, and then the cost of conveying the coal, including of course in the latter the expenses of maintaining the plant in working order. In Great Britain the charge made by the railway companies is about three-fourths of a penny per ton per mile, though in the longer distances the rates may lessen because the terminal charges bear a less proportion to the general expense. In Great Britain the coal is generally conveyed in the colliery wagons or in those of the buyers, although some railway companies prefer to use their own wagons. While in Great Britain the cost of railway carriage is not less than a half-penny per ton per mile, in the United States, owing to the cheaper railroads and to State subsidies in land and money, the cost is in some cases as low as one-third of a penny per mile for long distances.

Transport of coal.
See pages 533 *&* 727.

Canals and railways.

Water carriage is much cheaper than railway carriage. In Great Britain the canals, though they do not convey coal long distances, have considerable effect in restricting the railway charges when they come into competition, and the effect of sea carriage is still greater. Coal is brought from Newcastle to London by steamer 300 miles for from 3*s.* 6*d.* to 4*s.* per ton; from Cardiff and other Bristol Channel ports to the Mediterranean for from 7*s.* to 11*s.* per ton; from British ports to Bombay by steamer from 13*s.* to 15*s.* per ton; and to Brazil by sailing vessel for from 15*s.* to 20*s.* per ton. All these rates depend largely on the return freights which are available. Perhaps the cheapest water carriage is that from Pittsburgh to New Orleans by the Ohio and Mississippi rivers, the coal being taken in groups of barges or rafts in quantities of 20,000 tons for less than 2*s.* per ton for the whole distance of 1500 miles.

Rates of sea freight.

River freight.

Points to be considered in coal mining.

The following are the points which must be taken into account in deciding upon any coal-mining enterprise:—

1. Evidence as to the presence of coal having been obtained, the position, extent, and *Thickness of the seams* must be ascertained. If coal has been discovered within easy reach, the operations of working may in due course sufficiently disclose the above points and the value of the coal, but if considerable expenditure is proposed, such as for elaborate plant or the construction of railways, it is expedient to first ascertain the position and character of the seams, the likelihood of excessive water or other obstruction, and to settle some well-defined mode of working.

Character of seams.

2. The *Terms* on which the mining will be permitted, the tenure under which the land or minerals can be held, and the dues or taxes which will be payable.

Tenure of mine.
See page 344.

Quality of coal.

3. The *Kind and quality of the Coal*, as shown by its specific gravity, its hardness and texture, and by an analysis giving the

See page 528.

valuable as well as the useless and deleterious constituents, the evaporative powers of the coal, and the quantity of ash left after burning. The suitability of the coal for use as steam-engine fuel as well as for metallurgical purposes, depends on these points and (for use in smelting) also on the quality of the coke that can be made from the coal. The various kinds of coal, the chief purposes to which each kind is applied, the measure of quality which in each kind determines value, and the incidents of shipment and stowage, are referred to fully in another chapter.

Outlet for sale.

4. The existing or anticipated *Outlet for the sale* of the coal, namely, for what purposes it is likely to be used, the probable extent of the demand, and the quality and price of competing coal.

See page 74.

5. Information concerning the *Cost of labour*, pit timber, building materials and means of *Transport* available.

Copper mining.

Uses of copper.

Purity important.

Commercial designations.

Copper ore classified.

COPPER has three main uses: first, in the form of sheets, bolts, or nails for purposes where iron is objectionable because oxidative; secondly, for the innumerable alloys of brass, bronze and gun-metal; and thirdly, generally in the form of wire, as an electrical conductor. It is owing to the enormous consumption of copper for telegraph, telephone and transmission purposes, that prices have been maintained since 1890. For such electrical uses the purity of the metal is of the utmost importance. A mere trace of arsenic reduces the conductivity of copper by nearly one-half, and antimony, arsenic, phosphorus, nickel, or cobalt, in quantities even less than $\frac{1}{1000}$th part, alters materially the commercial value for brass alloys. It is according to the differences in these respects that copper is classed as "best selected," "tough ingot," and by other designations. Copper can, like gold or silver, be deposited as a film or coating by means of an electric battery. In prospecting for copper, the presence of the mineral may be proved in a simple manner by chemicals or by the blowpipe, and the exact composition of the mineral by careful analysis; but whether it is likely to be obtained in paying quantities can seldom be ascertained without considerable investigation and expense. The different kinds of copper ore may be broadly classed as follows:—

Native copper.

1. *Native copper*, as found in Chili, South Australia, and Lake Superior. The mineral which is found in veinstone in proportions ranging from 1 to 5 per cent., is obtained by the ordinary mining operations of excavating and blasting, the mineral being separated

from the rock by crushing and washing processes. The mineral when thus separated contains from 50 to 90 per cent. of pure copper, according to the thoroughness of the dressing. In the Lake Superior mines the average percentage of copper in the rock or veinstone seldom exceeds 2 per cent., but the dressed product averages about 80 per cent. of pure copper. Occasionally, however, in this district the copper is concentrated in masses of from a few pounds to hundreds of tons. These masses, when disengaged from the surrounding rock, are too pure and tough to be crushed by ordinary processes, and the great expense of cutting the copper into manageable pieces goes far to neutralise its apparent value; indeed, it is found that veinstone of regular quality containing from 1 to 3 per cent. of copper can be treated to greater advantage. Veinstone containing less than 1 per cent. of native copper can only be worked profitably when copper ingots are worth more than £40 per ton. Native copper, when mechanically separated from the veinstone, is free from the injurious ingredients that are found in other kinds of copper ore, and therefore can be immediately melted and manufactured into sheets, wire, and other useful forms, and such copper is especially suited for electrical purposes.

Percentage of copper.

Masses of copper.

Purity of native copper.

2. *Quartz*, containing 20 to 30 per cent. of copper in the form of oxide and carbonate mixed with sulphuret.

Quartz.

3. *Copper Pyrites*, containing from 5 to 25 parts of copper with sulphur and iron.

4. *Cupreous Pyrites*, containing about 48 per cent. of sulphur and from 3 to 5 per cent. of copper and iron.

Nine-tenths of the world's production is found in one or other of the forms above enumerated; but there are other varieties in the copper-bearing rocks, the chemical effect of contiguous minerals, of water, and other causes in past ages producing an infinite number of combinations. There is generally nothing peculiar in the mining operation for copper, the speculative element in this stage of operations being the proportion of sufficiently rich minerals which can be obtained from a certain amount of excavation. The processes of extracting copper from the various ores differ widely, but have for their common object the liberation of the copper not only from earthy matter but (except the pure native copper) from arsenic, antimony, sulphur, oxygen, and iron. Stamping, washing, roasting or calcining, melting, re-melting and refining, are the processes, but the methods not only vary according to the nature of the ore, the fuel, and other

Other varieties of ore.

Processes of extraction.

Methods, how determined.

local facilities available, but also with the object in view, namely, whether the obtaining of the copper is the chief or only object, or whether the other ingredients are to be saved. The cost of all these processes was greatly reduced in the years following 1870 in some of the Lake Superior mines; for instance, the stamping and washing of the ore, which prior to that date cost $5½ per ton, having been reduced to less than $1 in 1885, and the total expenses in producing refined copper having been reduced from *7d.* to *4d.* per lb.

Cost of stamping and washing.

Sulphur fumes.

Sulphuric acid.
See page 367.

In the calcining and smelting of copper ore, sulphurous fumes are released which are poisonous to vegetation. In the case of pyrites, when the making of sulphuric acid is the first object in view, these fumes are condensed in properly prepared chambers and saved; and in cases where no regard is had to the value of the sulphur, the nuisance of the fumes may be minimised by taking them through long and specially prepared flues in which much of the vapour is condensed, and by building high chimneys for the final discharge into the atmosphere. The latter precaution is always demanded where copper works are situated near towns.

Small operations unprofitable.

Transport of ore for smelting.

Ore calcined and concentrated.

Central works at Swansea.

Copper mining is not often carried on profitably on a small scale, nor, except under special and rare conditions, can the smelting and refining, considerable capital being needed to construct proper works for the treatment of the ore. If, however, the mineral is so rich in copper as to bear the cost of transport, there need be no other treatment at the mines than the selection of ore of sufficient quality and then selling it to smelters or others. In some cases a medium course is adopted; the ore, if it is rich, being calcined and smelted so as to get rid of most of what is deemed worthless, thus concentrating the mineral into a regulus or matte, containing 30 to 50 per cent. of copper, on which the cost of carriage bears less hardly. At the central copper works, of which those at Swansea are the principal example, ores of many different kinds are received, the variety affording certain advantages in mixing which no one kind possesses. One principal difference in the ores treated is the abundance or otherwise of sulphur contained in them, and very elaborate processes are adopted by which various other valuable by-products are saved, gold, silver, and arsenic being the principal.

Copper pyrites.

The extraction of copper from pyrites is associated so closely with the trade in sulphur that the two are to some extent interdependent, and cannot well be considered separately. As has been mentioned, the earlier processes of calcining and smelting release the sulphur in

Manufacture of sulphuric acid.

From Sicily brimstone.

Uses of sulphur.

Made from pyrites.

Spanish ore.

Purple ore.

Fall in value of sulphur.

Sale by units. *See page* 438.

the ore; and the manufacture of sulphuric acid, by condensing the fumes in chambers, is one of the most extensive branches of the chemical trades. Formerly the acid was made from brimstone, which is discovered in an almost pure state in various parts of the world, the volcanic sulphur of Sicily being the principal source of supply. The price of Sicily brimstone has fluctuated greatly; for instance, the price of the quality known as "best thirds," which is that most in use, ranged during the forty years ending 1896 from £3 10*s.* to £7 10*s.* per ton. The exact price at any particular time is determined more by the rates of sea carriage than by alterations of value at the mines. Formerly about half the product of the mines was imported into England, where by refining processes it is manufactured into flowers of sulphur, roll sulphur, and other marketable forms, as used in drugs, for making gunpowder and lucifer matches, for dressing vines or hops, and for various other purposes. Now, however, a much less proportion finds its way to England, for the manufacture of sulphuric acid from brimstone or native sulphur has very greatly decreased, as it can be made much more cheaply from pyrites. At the various chemical works established in the Newcastle, Liverpool and London districts, and at various places on the Continent, the pyrites are first sold to those interested only in the sulphur they contain, the numerous alkali and other works requiring sulphuric acid in large quantities. The residue or roasted ore, after the sulphur is extracted, is then sold to the copper extractors, who indeed are sometimes the original importers of the ore, who have sold it with the proviso that it shall be returned to them. The Spanish ores contain, besides the copper, a large quantity of iron, which is useful as a flux to mix with silicious copper ores; and the final iron residue, known as bluebilly, or purple ore, is purchased by iron smelters, who find that it can be mixed advantageously in the furnace with other kinds of iron ore. The trade in pyrites is mainly in the hands of a few large mine owners, who often make contracts over long periods. In the twenty years ending 1888 there was a considerable fall in value, so that while pyrites containing from 47 to 49 per cent. of sulphur sold in 1875 for about 6*d.* per unit of sulphur per ton, this unit price had fallen to 4*d.* in 1888, and varied little from this price during the following years. At this rate the value of a ton of sulphur in pyrites was £1 13*s.* 4*d.*

The cost and market value of sulphuric acid fell greatly during the same period, not only by the increased and cheaper supply of pyrites, but by various improvements in the methods of manufacture and the lessened expense of nitre, and the value of various other products in which the acid is used, such as alkalies, superphosphate and manures, having fallen also.

Pyrites treated for copper only.

While large quantities of pyrites are brought to England and treated first for the sulphuric acid and then for the copper, a much larger quantity is treated at the mines for copper only. At the well-known Tharsis mines in Spain, the more extensive Rio Tinto mines there, and other similar but smaller mines in the same locality, the ore contains about 48 per cent. of sulphur and little over 3 per cent. of copper. As water from mines of pyritic copper ores yields metallic copper by precipitation on iron, so by the same principle the metal is obtained from cupreous pyrites. Up till about the year 1890 the calcining of the ore was deemed a necessary preliminary, the sulphurous fumes being entirely wasted with destructive effect on the surrounding vegetation. The residual ore is then lixiviated or washed till the greater part of the soluble copper is extracted, four or five years being occupied by this process. It has been found, however, that while, by calcining the ore, the earlier stages of this long operation are expedited, it does not greatly reduce the total period, and in 1897 it was becoming usual to merely expose the ore to the weathering action of the atmosphere during the washing process. The copper contained in the liquor thus obtained is precipitated in large tanks in which pig or scrap iron has been placed, and the copper is deposited on the iron, from which it is finally separated by washing and rocking. The precipitate contains about 70 per cent. of copper, from which pure metallic copper is obtained by melting and refining processes. By improvements in the above process, pyrites containing only 2½ per cent. of copper can be profitably treated.

Lixiviation of copper ore.

Copper deposited on iron.

Value of mines, how determined.

In considering the value of any new copper mines, the leading points that determine value and the probabilities of profit may be summarised as follows. The *Kind* of the ore as shown by careful analysis; the *Cost* at which the ore can be brought to the surface, and if its kind require it separated mechanically from other substances; the kind, abundance, and cost of *Fuel;* the nature and abundance of the *Water* supply; the cost of *Carriage* to a port and the freight to a market. If the calcining or smelting of the ore is in question, the likelihood of objection on the score of nuisance has also to be considered. If the manufacture of copper from pyrites by the precipitation process is contemplated, then the cost and abundance of the water supply become more important, as well as the cost of pig iron or scrap iron.

Saving in fuel.

Some of the inventions for treating pyrites ore have been directed towards a reduction in the amount of fuel required both in regard to the first treatment of the ore, and the remelting of the matte or regulus. Other improvements have been introduced, but even when all these points have been investigated, there yet remains one which it is impossible to calculate in advance, namely, the future fluctuations in the market price of copper. In the ten years ending 1870, leaving extreme and temporary rates out of question, the price of copper in London ranged from £70 to £90 per ton. But the product from the United States had grown from 5000 tons in 1860 to 74,000 tons in 1885, about half the world's supply coming from the United States and Chili. In 1896 the production in the United States reached 205,000 tons. After 1880 the opening out of new mines in various parts of the world, chiefly in the United States, the reduction in the cost of dressing the ore in the American mines, and the supply from the pyrites mines in Spain, so increased the supply, that notwithstanding a growing consumption, prices fell in 1887 as low as £39 per ton. In 1888-9 a combination of European capitalists who controlled the production and sale, forced the price up to £80, but there was a collapse in 1889 when prices fell to £38. Between 1890 and 1896 prices fluctuated between £38 and £60. There are only a few mines in the world that can produce copper at £40 per ton; even £45 is unremunerative to a large number; and though at Rio Tinto, copper from pyrites could probably be produced without loss for £30, the process is an unwieldy one and cannot be suddenly accelerated to meet an increased demand. On the other hand, it would appear that any price over £55 per ton must be due to artificial and temporary conditions.

Fluctuations in value.

Chili bars.

The price of Chili bars was, prior to 1889, the standard of market value at any particular time, the basis for this standard being a percentage of not less than 96 of copper, namely, rough or partly refined copper. Bargains being made on this basis, there was sometimes the anomaly in times of speculation that such bars fetched a higher value than other equally good kinds of copper. Thus in 1888 Chili bars being scarce were for a time selling for £11 per ton more than other kinds.

G.M.B. copper.

But this anomaly was terminated in 1890 by the recognition in the London market of other copper under the title G.M.B. (good merchantable brands) of equal quality.

Gold mining.
Standard gold.
Pure gold.
Invariable money equivalent.
Annual production.

GOLD has a value based on the normal price at the chief mints of the world, which for standard gold containing one-twelfth part of copper, or "22 carats fine," is £3 17*s.* 9*d.* per troy ounce of 20 dwts., each dwt. containing 24 grains. On this basis pure gold is worth £4 4*s.* 10*d.* per troy ounce, and when in an assay a certain weight of gold per ton of ore is stated, pure gold of this value is meant. Gold nuggets have been found so free from baser constituents as to be worth £4 4*s.* per ounce, but generally the gold as it leaves the miner's hands has still some slight admixture of rocky particles, or the metal itself is slightly alloyed with silver, copper, or other metals. Allowing for the degrees of fineness and for various minor expenses after the gold leaves the hands of the producer, a value of from £3 10*s.* to £4 per ounce, according to the trouble bestowed in dressing the ore, expresses broadly the price obtainable by the miner, and forms a basis for calculating the expenditure that can be afforded to obtain a certain quantity. At the value of £4 per ounce a grain of gold is worth exactly 2*d.*, and a dwt. is worth 4*s.* Gold being the almost universal standard of value, has alone among the commodities of the world an invariable money equivalent, the effect of an abundant or diminished supply taking effect slowly and indirectly in the altered purchasing power of the gold, namely, in a cheapening or enhancing of prices. So far as can be arrived at from the most trustworthy sources, the world's annual production of gold in the years from 1880 to 1888 was about 5 million ounces troy, worth about 21 millions sterling, and in 1894 the value had increased to 37 millions. In 1889 the gold mined in the Witwatersrand district of the Transvaal was 208,000 ounces, and by annual increments the supply from this source alone had risen in 1896 to 2,281,900 ounces.

Gold always native.
How distinguished.

Gold is always found native in a metallic state, generally diffused in small particles in the rock or other matrix which holds it, and frequently in combination with iron, silver, copper, and other metals. Gold is softer than silver, it is more ductile and malleable than any other metal, it is yellow, is not acted on by nitric acid, is malleable under the hammer, and cuts with a knife without crumbling.

There is no precise limitation of the rocks or soils in which gold exists, for it has been found in the rocks of every geological period; it is asserted indeed that gold exists in minute quantities in all kinds of strata, that all pyrites afford a trace of gold with the same certainty that all lead contains more or less silver, and that there is even a grain of gold in every ton of sea water. Gold is usually found enclosed in quartz and among the gravel, sand and other alluvial detritus forming the beds of existing or ancient rivers that have brought the gold from its original source in the rocks. In New Zealand and South Africa the gold is found in a hard conglomerate or natural concrete composed of alluvial deposits so compressed and hardened by time as to need crushing like rock before the separating processes. Probably 95 per cent. of the gold supply of the world is obtained from the above-named sources.

Gold in quartz.

Alluvial gold conglomerate.

Gold is by some supposed to grow in an unaccountable way. Districts and deposits which were supposed to have been exhausted have in the course of years again given gold in remunerative quantities. In many formations the particles of gold are so minute as to be invisible, and these in time are carried by percolating water until combining they become visible. From one or other of these causes the idea arises that gold is constantly in course of formation.

Growth of gold.

Gold is recovered in various ways, which, however, may be broadly divided into two categories.

1st. The *Placer* mining, or the washing of gold from alluvial deposits, beginning with the simpler methods of pan and cradle, and elaborated in more extensive operations of sluicing, hydraulicking and drift mining.

Placer mining. *See page* 373.

2nd. *Rock* mining or reefing, when the ore so obtained has to be crushed to liberate the confined particles to prepare them for separation.

Rock mining. *See page* 376.

Outside these two categories is the getting of gold which has been smelted from the ores in combination with silver, copper, and other minerals.

Most of the great discoveries of gold, notably those of Australia, California, and later of British Columbia, have taken place on similar lines. First, the finding of rich alluvial deposits which give good results for hand working; then, as these deposits get poorer, machinery is brought to bear; and finally, as the difficulties of working become greater, the quantity of gold obtained from a given quantity of ore compares so unfavourably with earlier results, that only by heavy expenditure on powerful appliances and extremely careful treatment of enormous quantities, can a profit be obtained. This description, however, does not apply to the gold mining in the Transvaal, where the ore has been of a uniform though moderate quality from the commencement.

Course of gold discoveries.

Transvaal gold. *See page* 378.

Alluvial gold, where sought.

Alluvial gold is generally sought in what are supposed to be the bars, hollows and bends in the rivers' courses, where particles of gold carried along by the water would naturally subside by their weight. Geological knowledge and miners' experience allow probable conclusions as to the locality of these places to be drawn from surface signs, which may be further proved by examining the stratification of prospecting pits in these favourable places, in what may have been the course of an ancient water-course long since obliterated.

Specific gravity of gold.

Gold weighs about twenty times its bulk of water, while most of the gravel and other substances which hold it have a specific gravity ranging from three to five, and the processes of separation depend upon this difference in weight. The placer miner, who works by the simple plan of pan and cradle, washes the auriferous stuff, and gradually eliminating the light dirt, finds his prize at the bottom of the pan or cradle. Occasionally lumps of conglomerate or nuggets are met with, mainly composed of gold, but frequently in such cases allied with small proportions of silver and perhaps copper.

Nuggets.

Mining unremunerative on small scale.

It is seldom that the cost of gold mining can be brought within profitable limits, except by the aid of mechanical appliances on a considerable scale. First, for the getting of the auriferous gravel, excavating and hoisting apparatus of various kinds may be necessary; then appliances for washing and amalgamating, some of them of an elaborate kind, are combined with long sluices, in which bars or riffles arrest the heavier sediment containing gold particles. The separation of the smaller flakes and flour-like particles of gold is assisted by passing the wash-dirt over or through quicksilver, at various stages of the washing and sluicing processes, the amalgam being afterwards treated in furnaces which vaporise the mercury and leave the gold behind, the mercurial vapours being condensed and saved for further use.

Separation, how effected.

Cost depends on water-supply.

The nature of the water-supply goes far to determine the cost of these operations, the subsidiary expenses of pumps, conduits, flumes, dams, and other apparatus forming often a large proportion of the total expenditure. Where the water is not sufficiently plentiful at the place where the gold is found, it is generally cheaper to convey the water to the wash dirt than to carry the latter to the water, but when the course from the mine is directly down hill, transport may generally be cheaply arranged by constructing a self-acting incline, using the gravity force of the ore as the motive power. Where the auriferous gravel is hard or the percentage of gold low, mining ceases to be remunerative, unless circumstances are favourable to hydraulic or drift mining.

Low-grade ore.

In placer mining, where the average result falls below half an ounce of gold per cubic yard of gravel, the inducement to continue working with the simpler washing pan or *batéa*, which may be taken as the rudimentary form of hand labour, soon ceases, the precise point depending on the difficulties of obtaining a good water-supply, and the standard of wages in the locality. In California it has been reckoned as an approximate average that placer mining by pan costs per cubic yard of gravel the equivalent of three days' wages for one man; that by the use of the cradle the cost is at once reduced to three-fourths of a day's wages, that this three-fourths gradually lessens to one-fourth of a day as the larger and more elaborate "long Tom" or other cradle machines are used; and that by the use of long sluices and by hydraulicking the cost per yard ranged downwards from 1*s.* to 3*d.* per cubic yard of gravel treated.

Limits of profit in placer mining.

Cost reduced by machinery.

Hydraulic mining or "hydraulicking" is the application of jets of water at high pressure to the scouring away of gravel or other gold-bearing earths, the débris then being directed into conduits or sluices, where by means of one or other of the various applications of the methods already referred to, the gold is deposited and saved. Quicksilver is an indispensable adjunct; it is run into the sluice, where it seizes on and amalgamates with the gold that is deposited on the block bottom. It is, however, powerless to arrest light floating particles, and this "float-gold" constitutes the greatest item of loss in this method of recovery. Hydraulic mining was at one time applied widely and successfully in California, where it was for many years remunerative under a combination of special circumstances rarely to be found. The principal conditions are :—Abundant water at high elevations, and alluvial gold deposits at a level between that of the water supply and the tide, so that there is a downward course available for "dumping" the waste or tailings after the water is applied.

Hydraulicking.

Amalgamation.

As in California.

Conditions of success.

The works connected with the water-supply are so expensive as in many cases to form the subject of separate undertakings. Large impounding reservoirs, aqueducts, lines of piping, sometimes more than fifty miles in length, and other subsidiary works have been found necessary to the supply of water, which is then sold to the miners by a measure of quantity known as the "miner's inch." This

Costly works for water supply.

Water, how applied.

Profit from low-grade ore.

Favourable conditions.

Sludge channels.

is the quantity of water which will pass in twenty-four hours through an aperture of a square inch under a six-inch head or pressure, and is equal to 2160 cubic feet or 12,960 gallons of water, or about 58 tons weight. The water has a head of from 100 to 1500 feet, equal to a pressure of from 40 to 600 lbs. per square inch, and this when applied through a nozzle like that of a fire engine but much larger, against a vertical face of gravel, tears it asunder, and the disintegrated gravel is washed down the sluices. Water is generally considered as able to carry with it one-fifth its weight in gravel. As much as 500 cubic yards of water has been used for every cubic yard of gravel; but notwithstanding this, profits have been made from deposits affording only an average gold value of 4*d.* per cubic yard. The average in California is about one part of gold to twelve million parts of gravel, equivalent to a lump about $\frac{1}{8}$th inch cube for every cubic yard. Indeed, in cases where the water is at high pressure and cheaply obtained, the gravel easily broken up, and the other accessory conditions favourable, operations have been continued with a return as low as 3*d.* per yard. In California the success of hydraulic mining was due not only to these favourable conditions, but also to the circumstance of the country being unpopulated, no riparian rights and vested interests existing to hinder the miners in utilising the water-supply as they pleased, and no land occupiers below to be injured by the tailings from the sluices, which disfigured and destroyed the surface over a wide area. With growth of population and the opposing interests of agriculturists, much of the hydraulic mining as here described had to be stopped by legislation. In New Zealand and elsewhere these difficulties have been anticipated by the granting of mining concessions, accompanied by certain specific rights in the river lands below as sludge channels.

Drift mining.

Crushing of conglomerate. *See page* 378.

Where there is a consideable overburden of waste soil above the gold-bearing strata, the cost of scouring away the upper strata seriously reduces the average result, and it is sometimes found preferable to proceed by drift mining, which is the working of auriferous gravel deposits by shafts, adits and tunnels, somewhat as in coal mining, the gravel being obtained by pick and shovel, and then dealt with by water in sluices, as in the after processes of hydraulicking. Where the gravel and alluvial deposits have hardened into a natural concrete or conglomerate, the latter may require blasting to win it, and has sometimes to be pulverised by stamps, as is done in quartz mining, though not so finely. While, however, in hydraulicking the whole thickness of the gravel is dealt with, in drift mining only the lower auriferous part of the gravel is generally selected, the choice of methods depending mainly on the amount of waste or overburden, whether it is firm, or so soft as to need timber supports or entire lining, and, if so, whether timber is obtainable, and on the quantity and pressure of the available water.

Loss of gold in alluvial mining.

See page 350.

Rusty gold.

It is characteristic of alluvial gold mining by all the processes here described, that a considerable proportion of the gold is lost; and although in extreme cases this may be due to carelessness rather than to incomplete processes or appliances, there is always a point, to be determined by the experience of the miner, where the cost of further labour ceases to yield an adequate return. Among the main causes for the loss of gold are the incomplete breaking up of the gravel, there often being large lumps which remain unbroken, and the gold within them therefore untouched, and the "float gold" already referred to. Even in the best broken stuff some of the precious metal is in such small particles—flour of gold—as to be undistinguishable by the eye, and a portion of these escape, even though there be two miles of sluices and ample under currents. Another and fruitful source of loss is where the gold is "rusty" or coated with some substance which prevents the quicksilver acting upon it, and thus allowing considerable quantities of the metal to pass away with the tailings.

Weathering of ore.

Bulk unequal to sample.

See page 426.

Gold lost in tailings.

When gravel, rock, or lumpy earth of any kind is detached from its bed, a period of weathering (a year or more if possible), which is very seldom adopted, will so increase its friability as to assist greatly the disintegration by the washing processes. In the sluices also, where large quantities of stuff are dealt with, there is often insufficient time for the finer gold to settle or amalgamate. Even in perfectly still water, flour of gold will take an appreciable time to sink a few inches, and in the flowing water of a sluice, much of both flour and float gold are liable to escape. The foregoing remarks indicate that much of the loss of gold is due to hasty methods of working. Miners are disheartened when they find that the average yield of gold is 30 to 60 per cent. less than periodical assays disclose, and a careful treatment and assay of the tailings will prove the facts and show that the discrepancy is not due to errors or mis-statements in the first assays. Not only do Chinese and other cheap workers find profit from the tailings, but by means of recent improvements in hydraulic separation and other mechanical appliances, capital and skilled enterprise can be profitably directed to them.

Unequal distribution of gold.

Placer mining speculative.

It is necessary, when estimating in advance in any particular case the probable results of placer mining, to bear in mind that the gold is very unequally distributed, and that samplings taken from more numerous places must be examined than is necessary in prospecting quartz or rock veins; and secondly, that an exhaustive assay of collected samples is certain to produce more gold than can be obtained in practice on a large scale by any remunerative process. For these reasons, placer mining is uncertain and speculative, and although the total results may be beneficial to the country where the discovery is made, yet if the total cost of labour bestowed on it were measured in wages, the result would, with few exceptions, be lower than that gained by the ordinary labour of the country at the time. Still the large prizes that are gained by the fortunate few will always render placer mining attractive.

Rock or reef mining.

Testing of gold quartz.

The second category of gold mining referred to on page 371; namely, " Rock " mining, or the obtaining of gold from the original veins, differs materially from the placer mining just described. Gold can seldom be profitably obtained from quartz, the form of rock in which the precious metal most frequently occurs, except on a considerable scale. It follows, therefore, thatal though capital may be judiciously expended on plant and machinery when the real facts of the case are known, the loss is the greater should the mine prove unprofitable. For this reason preliminary exploration is especially necessary; and in many cases a little more time spent in thorough prospecting, and a comparatively small outlay in machinery for testing the ore will solve doubt and save much disappointment.

Variety of auriferous veins.

Testing by mining and assay.

The cost of getting obviously depends, as in the case of other minerals, on the depth from the surface, the amount of waste stuff to be removed, obstruction from water, cost of labour, and other local incidents. There is an infinite variety of auriferous veins, and although the science of mining and the theories of metalliferous veins based on varied and accumulated experience assist greatly in the development of gold mines, and although in certain rocks the absence of gold may be positively declared, the range is so wide within which there is a reasonable possibility of gold, that the search for gold will always be speculative and uncertain. In hundreds of miles of quartz rock there may only be a few districts in which gold can be obtained in remunerative quantities, and these can only be ascertained by sampling, that is to say, by actually mining and assaying the rock. The auriferous reefs may crop out on the surface, and extend for hundreds of feet below it, or the surface indications, as in some parts of the East Indies or Brazil, may extend but a very few feet down, or there may be a strong vein below without any surface indications. There is not only a wide difference in the cost of getting the ore under these various circumstances, but the great uncertainty as to the extent of the veins renders it difficult to judge how far they will repay the cost of extensive plant.

Cost of getting varies.

Prospecting in advance.

Diamond drill. *See page* 822.

Ancient workings. *See page* 348.

For these reasons, and as has already been indicated, prospecting in advance should always precede any large expenditure on plant. The diamond drill offers great advantages for prospecting in rock where there is sufficient water supply for the drill and the ground is not too irregular. In countries like Australia, opened out for the first time by civilised explorers, there are only natural signs to guide the search; while in India and other Eastern countries, not only does tradition point to certain places as bearing gold, but there is also the evidence of ancient workings. Expenditure at such places is encouraged by the hope, though it often proves fallacious, that modern appliances may allow a profit unattainable by ancient and ruder methods, or that deeper excavations may expose new gold-bearing strata.

Varying richness of mines.

Cost of getting, how determined.

It is impossible to fix any standard as to what amount of gold will repay the cost of obtaining it. Many of the richer mines of the world, in Australia and elsewhere, have averaged from 2 oz. to 10 oz. per ton of ore, with occasional greater prizes. In Victoria, Australia, the average of all the mines in the colony is about ½ oz. per ton of ore treated, while in some parts of Victoria, as also in America, mines continue to be worked at a profit with only 3 to 6 dwts. of gold per ton. The cost of getting varies with the depth, the hardness of the rock, the amount of waste to be removed, and other local circumstances, and the expense of crushing the ore will in some cases be ten times what it is in others. An outlay of from 10*s*. to £10 per ton of ore are limits not too wide for the great variety of circumstances under which gold mining is profitably conducted

Poor ore may pay on large scale.

Mines worked profitably with poor ore may pay, because large quantities are produced day by day so as to keep numerous stamps at work, and because owing to cheap fuel or water power the machinery is cheaply driven. But although economy may be obtained by carrying on operations on a large scale, much depends on whether the machinery can be regularly worked to its full capacity. If there is not always a full supply of ore for the stamps, or if the separating processes cannot keep pace with the pulverising, then the cost per ton of ore is at once increased.

Crushing of quartz.

Quartz and other rocks containing free gold have first to be broken up. This process of reduction commences with throwing the ore as it leaves the mine on to large inclined grids or "grizzlies," and taking the larger pieces thus separated to one set of stone breakers, and the smaller pieces to another set, and the ore thus broken passes automatically to the stamps, where it is pounded in water. After the ore is pulverised to the size of sand, the gold is obtained by elaborate processes of percussive shaking and washing, and by the aid of mercury in various ingenious machines by which the gold is seized and retained till it is finally separated in retorts by distillation, as already described. In America 100 gallons of water per stamp per hour is a fair average; in Australia ten times this quantity is sometimes used, but excessive use of water sometimes wastes gold by washing it away. The water from a stamp battery cannot always be reckoned on as available for re-use, as it will take up sulphur and other impurities which "sicken" the mercury on the plates. The cost of separating the precious metal from the quartz depends on whether it is free gold or combined with other substances, on the friability and other characteristics of the ore, on the quantity and quality of water available, and on the supply of coal or other fuel.

Washing and sifting.

Water, quantity required.

Expense of separating gold.

Transvaal gold.

The discovery of gold in the Witwatersrand district of the Transvaal, and the enormous developments of mining operations there since 1888, rendered possible by the abundant contiguous coal deposits, led to considerable modifications of previously existing methods of gold recovery. The "banket" formation in the Transvaal, although outside the ordinary definition of either placer or rock mining, may perhaps belong to the first, while it undoubtedly demands the treatment of the second. Banket is the Dutch name given to the particular conglomerate of quartzite pebbles, held together by a silicious cement which contains the gold partly free and partly attached to the latter, varying in amount with the depth at which the reef is mined. The gold is held in the grasp of the pyrites, and about two-thirds of it is recovered by the usual methods of crushing, stamping, and amalgamating with mercury. The "pulp" flowing away from this process is either concentrated and the "concentrates" treated by chlorination or frequently without concentration by the cyanide process. By this invention and its subsequent developments, the gold which is not caught by the amal-

Gold, how deposited.

Methods of recovery.

gam plate of the battery, and the concentrators, is recovered by chemical solution.

See page 371.

The Transvaal mines are exceptional in the regularity of the yield of gold per ton. This ranges from 8 to 12 dwts., with occasional richer reef, the average of the whole district being about 10 dwts., or ½ oz. per ton of reef.

Capital written off.

Large equipment of 100 stamps.

Although in the extraction of gold from ore of any kind, profit appropriate to the risk is seldom obtainable when there is less than 8 dwts. to the ton, it will often pay to work mines and dressing plant already established for a much lower percentage. Where the capital sunk in plant, explorations and preliminary expenses has been written off out of past earnings, or where owing to past non-success a mine has been transferred to a new company with little or no burden of past capital, then bold and economical management on a large scale may show a profit otherwise unattainable. Under circumstances such as these, with an equipment of 100 stamps and upwards, with other plant in proportion, and with a constant and steady supply of ore to keep all the stamps employed, quartz yielding only 3 dwts. of gold per ton has given satisfactory results; but such a small rate is quite inadequate in the vast majority of cases, and it will rarely be found that ore giving even twice that quantity of gold can be worked to cover expenses.

Iron mining.

Where profitable.

IRON ore has little or no intrinsic value by itself, and is worth the getting only when there is contiguous fuel for smelting, or when the ore and fuel can be brought together at small cost; and even under these conditions there must be a market for the product within easy reach. In other cases also ore is valuable where it is of such a special quality and is so situated near the sea or other cheap means of transport as to repay the cost of carriage to places where there are existing furnaces. Where there is contiguous fuel, iron of fair quality is pretty certain to be eventually used, but mines situated inland can seldom compete in the markets of the world, and till a local demand arises for the finished product sufficient to pay for the cost of manufacture, such iron will remain unworked. Iron ore is often carried cheaply as ballast.

Carriage of ore.

Wire-rope carriers.

For carrying ore a few miles to a port or to furnaces, various methods are employed where no railway or water carriage is available. In Spain much of the ore is transported in panniers by mules or donkeys. Wire-rope carriers are also often used with advantage.

In England, France, Germany, and Belgium, and in all the districts where coal and iron are found within a reasonable distance of each other, and even where the iron is not of the richest or purest kind, it can be worked profitably, because it can be made cheaply and can be easily carried to a market.

Prospecting. In prospecting for iron ore its presence or proximity is sometimes very plainly manifested, and the ore is often exposed on the surface of the ground. Oxide of iron is shown in the colour of the soil, in the colour and taste of the water, in the nature of the vegetation; **Indications.** these signs being frequently sufficient to justify trouble and expense in further investigation. But except by its weight the ore often affords no outward sign of iron, and remains undetected; although the mere burning of it with wood fuel, even at a moderate temperature, would sufficiently reveal its nature.

Classification of iron ore. The numerous kinds of iron ore may be broadly divided into two main classes.

Carbonates. 1st. Ores in which the iron exists as carbonates.

(*a*) Spathose ore, as in Carinthia and Styria, where it is smelted with charcoal fuel.

(*b*) Clay ironstone, as in Cleveland or Middlesbrough.

(*c*) Blackband, as in South Staffordshire and Scotland.

Oxides. 2nd. Ores in which the iron exists as oxides.

(*d*) Magnetic ore, as in Sweden and Russia.

(*e*) Red hæmatite, as in Cumberland and Lancashire, Campanil (Bilbao), and Elba.

(*f*) Brown hæmatite, in which the oxide is combined with water, e.g. Rubio (Bilbao), and Northamptonshire.

Manganiferous ores. (*g*) Manganiferous ores, in which some of the iron is replaced by manganese, e.g. Cartagena (Spain).

The ores in this second class are distinguished from those in the **Steel making.** *See page* 383. first class (except *a*) as being free enough from phosphorus for making steel by the ordinary or acid process.

Of the above two kinds of ore, those marked *b* and *c* in the first **Ores found in coal measures.** class are those which are found in the coal measures of central England; and although they only afford from 20 to 40 per cent. of metallic iron, their contiguity to coal and limestone renders them valuable. These ores are worth from 5*s*. to 12*s*. per ton delivered at the smelting furnace, the price varying mainly with the cost of **Clay ore roasted or calcined.** carriage. Clay iron ore is generally roasted as a preliminary to smelting, and the blackband ore in this class contains enough carbonaceous matter to serve as fuel for the roasting. Where this is not the case, small coal is added to the heaps of ore, as is done to clay when burning it for ballast. By this calcining process the clay ironstone loses about one-fourth of its weight, and blackband nearly one-half, and the roasted ore contains from 10 to 30 per cent. more iron than when raw. Sometimes the ore is calcined in kilns.

Magnetic oxide.

In Class 2 the richest ore is the magnetic oxide of iron found in Sweden, but the rock formations in which it is found do not contain coal. The iron made from this ore with charcoal fuel is of the highest quality.

Spanish hæmatites.

Manganese ore.

Sale by units. *See page* 438.

Besides the Campanil red Spanish ore belonging to the red hæmatite class and the brown Spanish Rubio ore belonging to the brown hæmatites, the manganiferous ores found at the Porman mines in the vicinity of Cartagena may be classed as hæmatite, in which the oxide of iron is replaced by oxide of manganese. These ores are sufficiently free from phosphorus to serve for steel making. The Porman ore is sometimes sold by the compound units of iron and manganese, the latter constituent rendering it useful for the manufacture of spiegeleisen and ferro-manganese.

Red hæmatite.

Non-phosphoric.

Suitable for steel.

Phosphoric ore. *See page* 384.

Basic steel. *See page* 384.

Bilbao ore.

The red hæmatite ore is found in various parts of Great Britain, but in paying quantities only in North Lancashire and Cumberland, where it is found in thick masses, some of it in specular kidney-shaped nodules. This ore varies considerably in richness, the percentage of iron varying from 50 to 60 per cent., and it is the only ore in Great Britain sufficiently free from phosphorus for steel making, as ore containing more than 0·04 per cent. of phosphorus cannot be made into good steel either by the ordinary Bessemer or open-hearth processes. Phosphoric ores are, however, available for steel by the basic process. This English non-phosphoric iron is quite inadequate to supply the growing demand; and consequently steel-making or "Bessemer ore," as it is sometimes called, is valuable wherever it is found in places accessible to cheap carriage. The principal source of supply for Europe is the Campanil ore from Bilbao, where the price has fluctuated from 5*s*. to 10*s*. per ton, and the carriage by steamer to an English port from 4*s*. to 6*s*. per ton. In 1895, 3½ millions of tons were exported from Bilbao to Great Britain, this being a considerable increase over previous years. But the total export had not increased, and as the ore, of good quality and within easy reach for shipment, was then already fully worked, any further increase will probably be attended by a greater cost.

Elba ore. In this division of the second class is the specular iron found in the island of Elba. This iron occurs in large bright steel-looking masses; it contains about 60 per cent. of iron and very little phosphorus. The mines belong to the Italian Government, and the produce is sold yearly to the highest bidder, the price including the cost of delivery on board ship having ranged from 8*s.* to 12*s.* per ton. **Letting of mines.** *See page* 346. Up to the year 1888, five-sixths of this ore was shipped to the United States, but the need there for European ore has been restricted by the development of American mines and by those in Cuba. Northamptonshire ore belongs to this class; it has a low percentage of iron, and contains much phosphorus. **Irish Ore.** Irish (Antrim) ore is used in small quantities with other ores, as it contains much alumina and is useful as a flux.

Cost of getting. The cost of getting ore varies according to the formation in which it is found, its abundance, and other circumstances. Ironstone is found in seams or layers of from a few inches up to many feet in thickness, occasionally also in pockets, or as nodules in clay. The cost of getting depends mainly upon the depth from the surface, the amount of waste to be removed, the hardness of the ore, and other usual incidents of mining. **Prospecting.** Prospecting by the excavation of trial-pits, or, if the depth be great, by the diamond drill or other boring apparatus, is necessary to ascertain the thickness of the seams and the area covered. In many of the formations there is the risk that what appears likely to be a seam extending over a wide area is only a pocket or deposit of limited extent, which will not repay much expense in sinking shafts and other operations. **Pocket deposits.** Such pocket-like deposits are particularly frequent with the richer manganiferous ores. Approximately every inch in thickness of the ore gives a weight of 200 tons per acre. **Weight of ore per acre.** Sometimes the ore is found in large masses, which can be obtained by open quarrying or by cutting down the face of a cliff. In cases such as these, little mining skill or experience is needed; and in many such cases, e. g. Middlesbrough, Bilbao, Elba, Cartagena, the ore is situated very near to the sea. **Ore near coast.**

Smelting of iron ore. Whatever the ultimate purpose of the iron, it is almost always made first into pig iron, the exception being where the iron while in its first molten condition is occasionally converted directly into steel. **Varieties of pig iron.** *See page* 539. Pig iron, while depending for its quality primarily on that of the ore and the fuel with which it is smelted, varies also according to the proportion of the fuel, the kind and quantity of flux employed, and the operations of the furnace.

Bessemer steel. The Bessemer invention of steel making, the simplicity of the

Phosphorus. *See page* 381.
British ore. *See page* 380.

process, and the rapidity with which steel made by it and the other processes growing out of it have superseded wrought iron for rails, ships, bridges, boilers and other purposes, have greatly altered the conditions of the trade in iron ore. Most of the iron ores in Great Britain, as in other parts of the world, contain so much phosphorus as to render them unsuitable for steel making by the ordinary or acid process.

Spanish ore.

Scale of prices.

American iron-making.

Iron in Southern States.

Not suited for steel.

European ore sent to United States.

Price depends on freight. *See page* 379.

In Europe non-phosphoric ore is obtained from Bilbao on the north, and Porman on the east coast of Spain; also from North Africa, and Elba, the mines in all these places that furnish ore for export being situate close to the sea, and at places accessible for vessels. Of all the varieties of ore so shipped it may be said that they contain from 50 to 60 per cent. of metallic iron, not more than 0·04 per cent. of phosphorus, and that the price delivered on board an export vessel ranges from 5*s.* to 12*s.* per ton, according to quality and the fluctuations in the market price of steel and sea freights. Sometimes the price is by scale according to the percentage of iron in each cargo. In the United States, Pennsylvania has been the chief seat of the iron trade, mainly because of the abundance of fuel and because suitable iron ore can be brought long distances thither by lake steamers, and also so cheaply by rail as to allow of profitable working, especially when protected from foreign competition by protective tariffs. The trade is rapidly spreading into other parts of the country, especially in the Southern States, where vast fields of iron ore and coal are found in close proximity, only waiting for a demand within reasonable distance for the pig or finished iron to render them profitable. Alabama, Kentucky, Tennessee, and West Virginia are all iron-producing States. But in all these districts, as in Europe, the largest deposits of ore almost always contain too much phosphorus for steel making. Pending the discovery and actual working of purer ores in other districts, non-phosphoric ore has been imported in large quantities from the various districts in and around the Mediterranean that supply the European steel makers. The export of Bilbao iron ore to America has been limited, because the port is not well suited to the large vessels crossing the Atlantic; but Elba, Porman, and North African ores have been shipped thither largely. The cost of Atlantic freight has ranged between 8*s.* and 14*s.* per ton, and the fluctuations are greater and more frequent than those in the price of the ore. The risk to those who buy and sell the ore lies therefore mostly in the transport. Large mines of steel-making ores have been opened out in Cuba exclusively for America, but the absence of return cargoes to the island has enhanced the cost of freight.

Duty on ore.

Formerly the import tax in the United States of America was by an ad-valorem duty of 20 per cent. which produced from 1*s.* 2*d.* to 3*s.* per ton; the tax was altered to a fixed rate of 3*s.* about 1885, and to 1*s.* 8*d.* (40*c.*) in 1897. There is, of course, the inland carriage to pay also, and, according to the activity of the demand and the fluctuations in the price of native ore does the European ore find its way a greater or less distance inland from the coast.

Basic process.

Converter lining.

Basic process in Germany. *See also page* 557.

Phosphoric ore is available under certain conditions for steel making, for by the inventions of Gilchrist, Thomas, and others, the phosphorus is abstracted during the process of converting, and steel of good quality is made. Shortly, this process consists in adding a considerable quantity of lime during the process of conversion, and in giving a refractory lining to the converting vessels to allow the use of the lime. This is sometimes known as the "*Basic process,*" as distinguished from the ordinary or "acid" method. The "basic" plan can be applied either to the Bessemer or to the Siemens or open-hearth processes, but it adds somewhat to the trouble and expense, and the competition between the acid and the basic methods depends mainly on local conditions. Thus while considerable quantities of basic steel are made in England, yet at steel works on the coast, Spanish and other pure ores can be imported so cheaply to supplement the Cumberland ore, that a much less proportion of basic steel is made than in Germany, where native or imported pure ores are dearer. As invention progresses these incidents of locality and cost may alter.

Mixture of ores.

A mixture of different kinds of ore is almost always more advantageous than smelting one kind only. Ore which is hard and stubborn, or ores having excessive silica, may be mixed advantageously with ores of opposite kinds. For this reason there are certain ores which cannot be utilised profitably where they are mined, although there be suitable fuel available, but which may be sometimes exported with advantage to places where a particular kind of ore is needed to mix with other kinds.

Condition of ore when shipped.

Carbonate or clay ironstone and blackband ores are the only kinds requiring treatment (roasting) before smelting, and the iron oxide ores, if for export, may be taken directly from the mine to the vessel for shipment. Some of these ores must however be broken, either in the getting or afterwards, into moderate-sized pieces, as it is seldom that pieces more than about 28 lbs. weight are placed in the furnace. Other ores are so mixed with earthy substances as to need washing, a process which to be performed effectually and cheaply requires special apparatus, and so cheap a commodity as iron ore will not bear a great expense.

Washing ore.

Basis of value.

The primary basis of value in the purchase of ore is the proportion of metallic iron it contains, and then its freedom from objectionable constituents, these facts being ascertained by analysis. When once ore from a certain mine is well known, it is generally accepted by neighbouring purchasers without guarantee of quality, and the ore or the iron made from it is subjected only to occasional analysis. Exported ore is always analysed on its arrival at its destination. The price of iron ore is sometimes a rate per unit of iron per ton of ore, so that every unit above an agreed minimum is paid for. The more costly the carriage, the more important does this condition become, as freight has of course to be paid on the gross tonnage. Some ores absorb much more moisture than others, and not only is the weight thus unprofitably increased, but if so used in the furnace there is loss of fuel in evaporating the moisture. As a common basis for assay it is usual to dry the samples at 212° Fahr. Where the ore has valuable ingredients besides iron, such as manganese, the price may be based on a sliding scale of each.

Analysis and sale by unit.

See page 438.

Samples dried to 212°.

Sliding scale.

See page 439.

Although the enterprise of mining, including the breaking and washing of the ore when necessary, may be kept quite distinct from the smelting and later processes of manufacture, yet it is often necessary, in order to realise the value of the iron, to establish furnaces and other works. The main item in cost of iron making is fuel, and as the most important factor in the absorption of heat is the slag or non-metallic portion of the ore, the richer the ore the less fuel is required per ton of iron produced. And if the ore has to be carried any considerable distance, then the useless weight obviously involves expense.

Establishment of iron furnaces.

Charcoal iron.

Obsolete in Europe.

The best iron is made with wood charcoal fuel, which is free from sulphur, but in the European iron-making countries the wood has been long ago exhausted, and though charcoal iron is still made in Sweden, Austria, Russia, and elsewhere, for special purpose, the quantity is very small. But there may possibly be a revival in this respect in newly developed iron districts where the ore is found in the midst of forests, such as is the case in Alabama in the United States, and elsewhere. But even where there is abundant timber for charcoal the consumption is so rapid (one acre of forest only affording from 7 to 14 tons of charcoal) that the distance from the furnace becomes greater and the expense of transport grows. In the United States charcoal costs about 25*s.* per ton at the kilns, in Austria about 35*s.*, and in England about 45*s.* About one ton of charcoal is required to make one ton of pig iron from the kind of ore usually melted with this fuel. Charcoal iron is not only the best for making wrought iron and steel, but when remelted in the foundry gives iron of a tough quality, very valuable for many purposes. Charcoal iron has, however, been almost entirely superseded by steel made by the modern processes. In the majority of cases coal is the only fuel available, and its abundance and quality are the first points to be considered. Anthracite and other kinds of hard coal not too bituminous can be used in a raw state for smelting iron, but most kinds of coal are quite unsuitable as mined, and must be coked before using, this involving considerable capital expense for ovens and the current cost of making. Coking ovens with their accessories costing about £50 each, produce about 30 tons of coke per week, an average of 27 to 30 cwt. of coal being used for making 1 ton of coke. The value of the coke depends not only on its calorific power and its freedom from sulphur, but also on its mechanical structure and consequent fitness for resisting the crushing strain in the furnace. In England the best coke is made in the Durham district from the bituminous coal, and the coke is taken for use to all parts of England, and is exported to foreign countries for metallurgical purposes. In the United States coke of a similar superior quality is made in the Connelsville district, near Pittsburg, at a much lower cost than anywhere else in the world, and conveyed hundreds of miles for metallurgical purposes. From 19 to 30 cwt. of coke are required for each ton of pig iron produced. The quality of the iron depends greatly on the character of the fuel with which it is brought in contact, sulphur being the most deleterious ingredient. Besides the fuel in the furnace, fuel is needed for the blast engine and for heating the blast. In almost all modern ironworks the waste gases from the furnaces are used for these heating purposes, and their utilisation for power by means of gas engines is likely also to be successful.

Charcoal iron in America.

Superseded by steel.

Coke fuel. *See page* 536.

Durham coke.

Connelsville coke.

Quantity of coke required for smelting.

Waste gases utilised.

Quality of flux.

Next to the fuel, the quality of the limestone or other substance used as flux is important. Sometimes the ore itself contains a flux as in the Frodingham (Lincolnshire) ironstone, where the lime averages 14 per cent.; and occasionally chalk, marble, or calcareous spar is employed. The kind of flux which is most suitable, and the quantity in proportion to the other materials, depend on the kind of ore and the proportion of iron, silica and sulphur that it contains, but although the quality of the iron is improved by using the most suitable flux, the choice generally depends on what is most easily found within reasonable distance. The quantity of limestone needed for 1 ton of pig iron ranges from 10 cwt. to 20 cwt. according to circumstances, but a less quantity is needed if much calcareous ore is used. Besides the transport of the ore already referred to, the local carriage to and from the furnaces is of consequence, the profit or loss to the iron-maker often depending on a saving of a few pence per ton. Including the ore, the fuel and the flux, from 3½ to 5 tons of material have to be moved for each ton of iron made, and there is besides the carriage of the iron when made, and the refuse slag.

Quantity of limestone required.

Weight of material for transport.

Iron-making.

Conditions of success.

Summarising the foregoing remarks, it will be seen that when an iron-making enterprise is contemplated in a new district, the kind, abundance, and cost of the fuel should be carefully ascertained. If the fuel is coal it is necessary to know whether it be hard or soft or friable, bituminous or anthracite, its calorific power, and its constituents as shown by analysis. The suitability of the coal for coking must be ascertained, and if possible an analysis obtained of the coke and its specific gravity. The limestone or other flux that is available should be analysed, as it is valuable according as it suits the ore and fuel with which it is to be mixed. The cost of fire-bricks or the proximity of fire-clay is of importance. A good supply of water is essential.

Vacant land for tipping.

Slag or dross.

Vacant land or tipping ground for the refuse slag from the furnaces has to be provided, and the locality of this land in relation to the furnaces, both as regards distance and level, is, together with the facilities for carrying, an important item in the economy of iron-works. Slag is useful for road making, and for concrete, but it is seldom that profitable use can be found for all the slag or dross that is produced. Basic slag containing phosphorus is valuable as manure.

Cost of making iron.

See PRICES OF IRON, *page* 539.

The cost of making iron depends a good deal on such a laying out of the works as will economise the movement of materials and facilitate the proper sequence of operations. Advantage may sometimes be taken of hilly or sloping ground to bring the materials by railway at a high level to the furnace mouth, and of a lower level for taking away the products. A carefully contoured plan, from which sections can be deduced, is necessary in order to design an ironworks correctly.

Lead mining.

LEAD is very seldom found native or pure, and of the numerous minerals in which it occurs only two are obtained in any considerable quantity, namely, galena or sulphuret of lead, and white-lead ore or carbonate of lead. The latter is probably a chemical alteration of the galena ore; it is often found with it, and is seldom smelted separately. Galena, which affords the main supply of the world, occurs in veins varying from many feet to a few inches in width, and sometimes in considerable masses, with other metallic ores in the primitive and secondary rocks, but mostly in what is known as mountain limestone. Galena is heavy, having a specific gravity of 7½, and is easily recognised, not only from its weight, but from the bright metallic lustre when broken up, and the rectangular form taken by the fragments. Two-thirds of British lead is found in carboniferous limestone, much of it in contiguity to shale, and it is also found in clay-slate and granite.

Galena.

Where found.

Lead heavy and lustrous.

Prospecting.

The prospecting for lead is in most cases not so difficult as for other minerals. The surface rocks often show by their colour the proximity of lead sulphide, and an analysis of neighbouring springs will show indications of lead in the water. In Europe most of the districts where lead is found have been worked in ancient times, and surface signs of old operations assist in new researches and developments. In Spain, which in 1889 furnished about one-fourth the world's supply, lead deposits are generally recognised on or near the surface, and old workings of superficial character requiring little or no pumping are usually available. But since 1890 the sources of supply have greatly increased, lead being imported into Great Britain from New Zealand and from silver lead mines in various parts of the world.

Surface signs.

Ancient workings.

Cost of getting.

The cost of getting is largely determined by the degree of hardness in the veins, by their regularity, and by their width. There is probably no other mineral in which there is so wide variation in the amount of ore in the same vein and in the same kind of rock as with lead. The expense of mining is made up of many items, which differ widely in different countries. In Great Britain the first burden is the royalty, tithe, or tribute payable to the State, the Church, or the

Mining expenses.

landowner. The royalty is generally in proportion to the ore found, and as the rate, especially in long leases, is based on the value and profits of a time when Great Britain was the chief source of the world's supply, this burden alone forbids any profit at many of the mines at the lower prices caused by foreign competition. Further, in the British mines many of the wider and richer veins have become exhausted, deeper explorations are hindered by the expenses of pumping, and the cost of labour is, as a rule, greater than in Spain, whose mines have been greatly developed, and where the royalties or Government dues are very moderate. Since 1880, the mining of lead in England has practically ceased.

Royalty. *See page* 345.

Mining in Spain.

Of all metals, lead is one of the easiest to separate from the rock which holds it. In Derbyshire most of the lead has been obtained by individual miners, who broke up the ore by hand, washed it in cradles, and sold the dressed ore to the neighbouring smelting works. But in mines worked systematically on a large scale, the ore is broken in stone-breakers and rolls, the varying gravity of the metallic and other particles being availed of, in washing machines elaborated from the simpler cradle of the miner. The ore having been thus dressed is roasted to expel the sulphur, arsenic, or antimony, and is then smelted in reverberatory furnaces and cast into pigs, which, if they hold sufficient of silver or other of the more valuable metals, are again treated, or are sold to the refiners, who desilver it. The cost of smelting depends a good deal on the kind and quality of the fuel available, and of the quartz, limestone, or other flux which is necessary to the smelting. Coke or coal fuel is generally used in Europe; shale also is used, and occasionally charcoal and brushwood in some of the remoter Spanish districts. In the United States charcoal is often available at a low cost, and its use offers certain advantages.

Dressin of lead ore.

Crushing.

Roasting.

Fuel.

The ore is always dressed at the mines, and is almost always smelted there also, though sometimes, where there are numerous small mines in a district, cupolas or other smelting furnaces are erected in some central place and deal with the whole produce. Occasionally, also, if got from mines within easy reach of a port of shipment, the ore is sent to smelting works in England, France, or Germany, where it can generally be treated to better advantage than at the mines. The ore is sold at a price per ton based on its units of lead, silver, or other constituents. The smelter has to take into account the gross value of the pig lead and silver, less the cost of

Smelting.

Lead ore. How valued.

carriage and smelting, the loss of lead in the process, interest on capital, and other obvious charges.

Constituents of lead ore. Pure lead ore, that is ore entirely freed from extraneous substances, contains 86½ per cent. of lead and 13½ per cent. of sulphur, any silver there may be taking the place of a part of the lead. In practice, however, the ore is seldom dressed purer than 80 per cent., and in the processes of roasting and smelting, antimony and other **Impurities.** impurities are not always entirely expelled. Much of the British lead was not desilvered, the proportion of silver being small, the lead in other respects being purer than most of the foreign lead. Where **Iron and silver in lead.** silver-lead is found in the neighbourhood of iron containing lead and silver, as sometimes happens, the iron ore may be used as a flux, and the lead is enriched by the metal taken from the iron.

Cost of smelting. In Great Britain the cost of smelting, exclusive of desilvering, approximates to 20*s.* per ton of ore treated. While most lead ore is smelted at or near the mine, it has not been customary to desilver the lead there; though in some of the larger foreign mines, the desilvering is also effected on the spot. Sometimes this is done only **Concentration.** partially by concentrating the silver with unrefined lead 60 to 300 oz. to the ton, the metal in this condition repaying better the cost of carriage to desilverers in London or elsewhere.

Changes in lead mining. The trade in lead has been revolutionised during the nineteenth century, first by the improvements in the processes of obtaining the silver from the lead, and since 1870 by the discovery and development of new mines of silver-lead in the United States. Up to the year 1870, Spain and Great Britain were the principal lead-producing **Increase of American lead.** countries of the world; lead found in the United States being not nearly enough for home consumption, the importation thither of lead amounting in 1870 to 42,000 tons. In 1880 the American production had so increased that the importation had fallen to 4000 tons, and the native production continued to increase, so that in 1884 it amounted to about 140,000 tons, of which six-sevenths was desilvered lead.

All galena contains sulphide of silver, ranging in quantity from 0·01 per cent., equal to 3¼ troy oz. per ton of lead, up to 1 per cent., equal to 326 oz. per ton. In the latter cases the ore is mined for **Silver-lead ore.** the sake of the silver, with little or no regard to the value of the lead. At the beginning of the 19th century silver could only be obtained from lead by processes which oxidised the latter and rendered re-melting necessary, and this was not remunerative even at the then high prices of both metals, unless there was at least 10 to 12 oz. of silver per ton of lead. As, however, by modern processes from 2 to 4 oz. of silver (according to the current prices of silver and lead) will pay for the separation, and as nine-tenths of the lead which is mined in the world contains such a proportion or more (although the lower grades are not always desilvered), it is evident that the value of so-called lead mines are estimated in a different way to formerly. Indeed, much of the lead manufactured into sheets and other forms before 1830 has a value for desilverising when sold now as old metal.

Desilverisation cheapened.

The processes by which the metals are separated cannot be fully described here. They consist mainly of three methods: First, the crystallisation of metal process, called Pattinson's process, taking advantage of the different behaviour of lead and silver at certain temperatures, the earlier formed crystals of lead being removed from the fluid silver. Secondly, the steam process, which though effective with certain combinations of metal is somewhat irregular in result. Thirdly, there is the zinc process, which though the most costly is the most scientific, reducing greatly the labour. If the proper skill be wanting this method involves loss. Advantage is taken of the affinity of zinc for gold, copper, and silver, to introduce the metal in such proportions as will exactly operate on these metals, which combine, and in cooling form a crust which can be removed, the fluid lead below being found free from its alloys. The zinc is then burnt off and the precious metal refined. Complex ores require special treatment.

Pattinson's process.

Steam process.

Zinc process.

Pig lead varies in character according to the extraneous matters it contains, and each kind has a use and value accordingly. British lead is generally pure, and can be used immediately for rolling into sheets, pressing into pipes or for caulking. Much of the Spanish lead is naturally hard from the antimony it contains, and although this may be removed during the processes of desilvering or by special treatment, a buyer requires assurance on this point, and the lead is accordingly warranted "soft" unless required as antimonial lead for type metal or other purposes. Sometimes lead of a kind inferior for ordinary use has a value because of its suitability for use in desilverising operations.

Quality of pig lead.

Antimony in lead.

From 1845 to 1849 the total production in Great Britain and the imports together amounted to an annual average of about 60,000 tons, and the average price was £17 13*s.* 9*d.* per ton. During the years 1873 to 1877 the average annual total was

Total production of lead.

Range of price.

about 145,000 tons, and notwithstanding this enormous increase the average price had risen to £22. In 1877, which may be considered as the last of the good years, pig lead sold for £20 10*s.*, and lead ore of average quality for £14 12*s.* 6*d.* In the next succeeding years the supply from Spain greatly increased, the manufacture of lead in Germany was extended, the opening out of silver-lead mines in Nevada and Colorado and the sale thence of large quantities of lead as a by-product rapidly reduced the price, and in 1885 the unprecedentedly low price of £10 5*s.* was reached. A large number of lead mines wholly or partially ceased working, and there was a recovery in value, and at one time during 1885 lead regained even as high a price as £12 15*s.* In 1896 the price of lead fluctuated between £11 and £11 15*s.* The exploitation of lead and silver-lead mines in different parts of the world, the peculiar fluctuations to which silver is liable because of its use in coinage, and the relation which a growing demand may have to an increased supply, will determine the price for the future. In 1896, 164,000 tons of lead were imported into Great Britain, while 41,000 tons of lead in pig, pipes and sheets were exported.

New mines discovered.

Silver lead in Colorado.

Exports and Imports.

Great Britain is recognised as the centre of the lead trade, and the prices of the London Exchange regulate those of the European markets, and, to a large extent, those of the United States also. But the greatly increased production of the latter country is tending to an alteration in this respect.

Lead market in London.

Silver mining.

SILVER is the brightest and most beautiful of metals; it is one of the most ductile; it is harder than gold, but softer than copper; and the facility with which it can be melted, and its permanency, have encouraged its use from the earliest times.

Silver ores.

Silver ore exists in most geological formations and in the rocks of all ages, but silver is found in combination so variously with other metals and mineral substances that the circumstances of production and treatment differ very widely. Native or metallic silver occurs very rarely, although some of the earliest and most famous mines were of this kind. Such silver is crystallised into cubes and other regular shapes, and sometimes these in minute forms strung together have the appearance of fibre threads or leaves. This silver ore proper is found in veins and pockets, and, as in other ores so found, the cost of getting depends greatly on the width, direction, and regularity of the veins and other deposits, so determining the amount of

Veins and pockets.

waste stuff to be removed in order to obtain a certain quantity of the ore.

Hand picking.

Some of the richer silver ores may be sufficiently separated by hand picking and directly smelted, but generally the rock has to be crushed and treated much in the same way as auriferous quartz. From the rock thus pulverised the silver, which has a specific gravity of 10½, may in some cases be directly obtained by washing and amalgamation with mercury, this for instance being the usual plan in Chili and Mexico, where the ore is sufficiently pure to admit of its being washed and treated mechanically without the roasting process, which for many classes of ore is absolutely necessary.

Amalgamation.

Sulphurets.

The larger proportion of silver ores are sulphurets, combined generally with copper, arsenic, and other sulphurets. Silver-bearing ores of these kinds require very careful assay to prove the presence of the metal, which in various states of combination is not visible at all as silver. It is in ore of these kinds that roasting is necessary. This is performed in reverberatory furnaces, where ordinary salt is mixed with the ore; the heat of the furnace vaporising and so expelling the sulphur, arsenic, and other volatile substances, which are afterwards condensed, and as far as possible utilised. When the ore is thus purified it is reduced to powder, and the silver is then extracted by amalgamation with mercury, the metal being separated in the usual way by retorting. The silver so obtained is in a porous condition, and is then melted in crucibles and cast into solid ingots. If, as is frequently the case, gold is combined, the more precious metal is separated by after processes of refining, seldom performed at the mine.

Roasting of ores.

Expels sulphur and arsenic.

Special skill required.

The profitable reduction of silver ore depends, more than in the case of any other metal, on the skill and knowledge brought to bear on the above processes. Not only are there numerous varieties of silver ore, but even in the same mine will various kinds be found, such as argentiferous iron, copper pyrites, as well as the different sulphurets of silver. It is not easy to judge these various kinds of ore by their appearance, and as the treatment in the furnace depends on the quality, it is necessary in order to obtain satisfactory results to assay the ore as it leaves the stamp battery, and then, by mixing the various parcels, to obtain for the furnace a charge of known average quality, which can be treated according to its kind. Some ores are more refractory than others, and for want of proper treatment, mines rich enough in themselves have for want of skill in roasting and

Great variety of ores.

Needing various treatment.

amalgamating entirely failed, the quantity of silver left in the tailings exceeding that obtained.

Costly machinery.

Proving of mines in advance.

The machinery and plant for the reduction of silver are necessarily costly, and though the outlay of capital may be amply repaid if the ore is sufficient in quantity and quality, failure has often occurred by establishing an expensive plant without sufficient investigation of the mine. It may be accepted as a rule that no outlay on reduction plant should be made on the basis of preliminary results, nor until, by actual prospecting in advance, enough ore has been proved to exist to repay the capital outlay proposed. Even after many years of successful working, prospecting should always precede further developments. If a mine is sold at a price, or on terms based on past profits, it may be found that valuable mineral can no longer be obtained in remunerative quantities.

Location of mines.

Transport.

The location and accessibility of the mine are also matters of great importance. If abundant water and fuel exist at or near the mine, and if there be no local hindrance to the establishment of works, the ore can be treated there, and the precious metal will repay the cost of even difficult transport as silver; but, if for want of local facilities for reduction, the ore itself has to be carried, then the question of transport becomes of the greatest importance. Rich silver mines are known to exist where they are valueless because of unfavourable conditions in these respects, and others, although worked, have entirely failed because these circumstances have been neglected or ignored.

Silver from lead.
See page 390.

Galena.

While the above may summarily describe the extraction of silver from its ores, a considerable proportion of the world's supply is obtained from lead, and to a small extent from copper. In such cases it is usual to obtain these metals by the smelting and other processes appropriate to them, and then to extract the silver by special treatment afterwards, this being most profitably effected at large central works, the principal of which are in England and Germany, where various grades or kinds of metals may be combined with advantage. In Spain and the United States a large proportion of the silver is obtained from argentiferous galena (silver-lead), and the earlier processes of mining and dressing are similar to those in a lead mine, with the difference that as the proportion of silver increases so can the expenditure on the various stages of getting, dressing and smelting be profitably increased. When the proportion of silver to lead is so small that the obtaining of the lead is the primary operation, the desilverisation is a later process carried on sometimes at the mine, but generally as a separate business by refiners or desilverers. The desilverising of lead and the changes that have occurred in the methods of doing it have been already referred to.

Desilverisation at mine. *See page* 391.

The refining of silver is most advantageously carried on by those who refine gold also. Each of the two metals frequently contain small proportions of the other, and the processes have been brought to such perfection that even two grains of gold in a troy lb. of silver will enhance the price obtainable for such silver.

Refining of silver.

Silver, like gold and unlike all other metals, is subject to peculiar incidents of enhancement and depression, because of its use as money, and, as these incidents are entirely outside those which affect other commodities, an element of speculation is added beyond the control of those interested in the mines. Silver has been the standard money of India and China, but it has ceased to be so in any other important country, although nominally it remains so to a partial extent in Mexico, South America, France and the United States. In the latter country the silver dollar was so long deemed the real standard of value that silver was considered worth its weight in coined money, and the richness of ore was expressed not in ounces but in dollars.

Fluctuations in price.

Standard of money in India, China and Mexico.

Without touching on the policy which has induced the demonetisation of silver in Germany and elsewhere, on the fluctuating supply of gold as a substitute, and on the feasibility of a double standard of value, which is so strongly advocated, the effect of such change on silver mining enterprise has been most marked and in some cases disastrous. At the beginning of the nineteenth century there was a fixed ratio of value to gold of 15½ (15·61) to 1, and this was upheld by the laws and operations of mintage in the leading countries of the world till the year 1870. Notwithstanding these laws and the considerable use of silver as a material of manufacture, the great increase in the production of silver on the one hand, both from the discovery of new mines and from its increased production as a by-product from lead, copper and other metals, and the growing preference for the less bulky gold on the other, caused the mints to restrict their silver coinage. The fall in the price of silver, while primarily due to the demonetisation of the metal, is obviously accelerated by the increased supply. Thus, in the years succeeding 1871, when Germany changed her standard to gold, the supply from American silver mines greatly

Demonetisation of silver.

Effect on values.

Over-production.

Comstock mine. increased. The Comstock Lode in Nevada alone produced in 1876 3½ millions sterling of gold and 4 millions sterling (taking the weight in equivalent dollars) of silver. In 1872 the ratio to gold was 15·63, and the price of silver was 60*d.* per troy ounce; in 1870 the ratio was 17·92, and the price of silver had fallen to 53¾*d.* In 1880 silver had from these causes fallen to 52*d.* per ounce. This reduction in value rendered many mines unremunerative, but the fall in values continued, in sympathy with that of all other commodities, during the following years, and was intensified by the vast product of the Colorado and other mines on the American Continent, so that in 1888 bar silver was only worth 42¼*d* per ounce, and the rupee, Mintage in India. nominally equal to 2*s.*, was worth only 16¼*d.* The free mintage of silver into rupees in India helped to maintain its price, but at the closing of the Indian mints to public coinage in 1893, silver fell further in value. In 1894 it touched 28½*d.*, and at the end of 1896 was at 30*d.* per ounce.

Future value. The future of silver, while depending greatly, as do the less valuable metals, on the consumption in manufacture and the growth of the supply, will be largely affected by the mintage regulations which may arise in Europe and America, and the permanence or alteration of the customs in British India and China. In Great Britain there is an import duty and corresponding excise tax on silver which artificially restricts its use in manufactures with little advantage to the Determining causes. revenue, but this duty is likely to be removed. The natural result of a fall in value, that the less profitable mines will stop working and so bring about an adjustment of the supply to the demand, is modified by the fact that much silver will continue to be produced as a by-product of other mineral operations, the desilverisation of lead and copper affecting the value of silver mines proper.

Tin mining. TIN is, for purposes of utility, next to iron, the most valuable of metals, and there are few sources of supply. Tin is hardly ever used alone, and its various uses may be broadly divided into five.

Uses of tin. 1. For the coating of iron and steel sheets to form "tin plates."

2. For coating tubes and vessels of copper or other metals to protect the surfaces from the corrosive action of acids.

Alloys. 3. As one of the chief ingredients in brass, bronze, and other of the innumerable alloys with copper.

4. As an ingredient in alloys with lead as pewter, solders and tin-foil.

5. In small quantities in various chemical mixtures.

Tin irrecoverable for re-use.

As tin is used almost invariably as an alloy with or as a coating on other metals, it can seldom be recovered and re-used, and there being thus no supply of old or second-hand material, as with most other metals, the demand for new is maintained and increased. The clean clippings from tin-smiths' new plates are, to a small extent, treated with acid for the recovery of the tin, but although there have been several attempts to obtain the tin from old tin plates, these have not as yet proved remunerative. It is probable, however, that by the aid of electricity this will eventually be accomplished.

Annual product.

Tin plates.

Taking the world's production of tin in 1887 as 45,000 tons, the consumption in Great Britain for tin plates was about 12,000 tons, the finished tin plates, to the value of 7 millions sterling, weighing 500,000 tons, of which about 80 per cent. were exported to the United States. The production of tin in Great Britain was about 9000 tons. After that date great changes took place in the economy of tin mining and the tin trade.

Cornish tin.

Eastern tin.

Australasian tin.

Fluctuations in value.

See page 369.

Up till the middle of the 19th century, Cornwall was the chief source of the world's supply, the quantity mined there exceeding greatly the aggregate from all the mines of other countries, although it seems certain that in ancient times the Indian and other Eastern mines now in operation were also worked. Since about the year 1860, however, the sources of supply have been greatly increased. The islands of Banca and Billiton near Sumatra, the mines in Malacca and other parts of the Malay Peninsula, have together furnished more tin than Cornwall. The low price of silver currency in the East greatly stimulated and further cheapened the cost of Malay tin mining. The development of mines in Peru, Bolivia, New South Wales, Victoria, Queensland, and the Mount Bischoff mines in Tasmania has still further increased the supply, so that the price of tin, which was as high as £159 in 1872, fell below £60 in 1878, and in 1885-6 fluctuated between £75 and £107. In 1887, English tin ranged from £104 to £150, while Australian and Straits tin had even wider fluctuations from £101 to £167. The higher of these prices in 1887 was due to an artificial combination of capitalists, who were also attempting to control copper, but the high rates could not be maintained, and the price fell to £76 in 1888. It did not again reach the high prices, and in 1896 fluctuated between £56 and £60. At these values the mining of tin in Cornwall is unprofitable, and many of the mines have been closed. The export of English tin and the re-export of foreign tin increased from 17,000 tons in 1887 to 26,000 tons in 1896, but the export of tin-plates fell gradually and continuously from 430,000 tons in 1889 to 273,000 tons in 1896, most of the reduction being in the export to the United States.

Tin ore always as oxide.

Tin never occurs "native," but always as an oxide, the only tin ore of any importance being the peroxide, which in its pure state, after separation from the rock or stone which holds it, consists of 78 per cent. of tin. The ore is found in the oldest rocks, principally in granite, and in Cornwall, generally below copper, at depths down to 2500 feet. Unlike copper, which in time alters and wastes under the chemical action of water and other surrounding influences, tin oxide is imperishable, although in the course of ages and under geological alterations its position changes.

Tin oxide. imperishable.

Lode tin.

In mining for lode tin, as the upper deposits become exhausted, excavations are made to deeper and older strata below. The veins or fissures containing the ore are sought for and followed as in copper mining, the stuff being brought up in vertical shafts or inclined adits. While the cost of dressing ore of a certain kind can be estimated within moderate limits, the getting of the ore, owing to the erratic nature of the deposits, is very speculative, although increased knowledge of the science of mine veins has done much to reduce the uncertainty.

Cost of getting uncertain.

Presence of tin, how proved.

As the ore before dressing generally contains only a small proportion of tin oxide, 1 to 4 per cent. embracing the majority of cases, the outward appearance of the ore does not always afford sufficient proof of its character, but the weight of the ore, as well as assays easily performed with the blow-pipe and simple chemical tests, declare with certainty the presence of the metal, although quantitative analysis requires great care and skill. Weight alone is not conclusive, as other minerals of almost similar weight are sometimes present.

Placer and stream tin.

By far the largest proportion of tin ore is derived from placers and alluvial deposits. Such ore is known as stream-tin, and is found amongst the detritus of weathered rocks in old or existing river beds, much as is the case with alluvial gold. While, however, alluvial gold is found on the surface, and at all depths, tin generally lies below the surface, and is covered in by a greater or less quantity of gravel or clay, and sometimes peat. Occasionally tin is found with some admixture of sand in crannies in the beds of running streams.

Mining for stream tin.

The mining for stream tin is conducted in various ways, depending on the depth and position of the ore. In the Malay districts, where

Bringing ore to the surface.

See page 831.

Over-burden.

Shafts and galleries.

Hydraulic mining.

See page 373.

the tin-bearing stratum is within 10 to 50 feet of the surface, the mines are worked in open cast, the native workmen removing the over-burden by digging, and the metalliferous deposit or wash dirt is carried to the surface in baskets. This system may be elaborated by various kinds of dredging buckets, elevators, or "grabs" worked by cranes or derricks, and sometimes the stuff is brought up by trucks on inclined planes. There may be two or more layers or deposits of stream tin, and these are generally mined together unless the false bottom of the upper layer should be mistaken for bed rock or finishing clay, cases having occurred where a second deposit has for a long time been unsuspected or unworked. The handling of the over-burden so as to minimise the labour requires careful consideration, and it is generally endeavoured to so work forward as to deposit the waste stuff in the open pit or quarry previously denuded of wash dirt. Another plan is to work by shafts or galleries as in a coal mine, so as to avoid the excavations of the upper strata, this plan indeed becoming necessary when the ore lies deep, but the cost of timber supports may render such mining unremunerative. Sometimes the vertical face of the open pit is undermined by a jet of water as in hydraulic mining, but, as also in gold mining, it is seldom that there is a combination of circumstances favourable to this plan. But even where the water is not of sufficient force to scour away the face of the excavation, the tin-bearing stuff may in some cases be shovelled into the water, which will carry it to a convenient sluicing place, partially separating the tin oxide in transit.

Malay mining.

The tin-bearing stuff found in the Malay country can be separated by washing and kindred processes, but "tinstone" as mined requires elaborate processes of washing and dressing, resembling in some respects the treatment of gold, but with this among other differences, that while pure or almost pure gold can be obtained by the miner, the ore when fully dressed contains only from 50 to 75 per cent. of tin oxide when sent to the smelter.

Ore in blocks, and as sand.

Crushing.

Roasting.

Tin ore when brought from the mine may be of all sizes, from large blocks of several hundredweights down to mere sweepings and fine sand. After being screened and sorted, the larger pieces are crushed by hammers or by machine-breakers, a preliminary burning in heaps being sometimes necessary to render the rock friable, and to expel the sulphur and arsenic, as in silver roasting. This roasting is almost always necessary with Cornish tin. Where the tin ore is mixed with copper or iron pyrites, such pieces have to be set aside for separate treatment, and the ore is then crushed by vertical stamps in boxes with water, asin gold and copper dressing. The ore after being crushed resembles black sand, and passes with the water through the small perforations of the stamp grids or grate plates, and is then subjected to a series of separating processes, all depending on the differences of specific gravity of the ore, and of the substances with which it is mixed. Although tin after smelting is one of the lightest of metals, being only seven times the weight of water, it is before smelting one of the heaviest of ores, and this assists greatly in the dressing.

Sands and slimes.

The sands and slimes from the stamp battery are caught in settling tanks, which sort and partially concentrate them into coarse and fine grades. Then follow further processes of separation, the sand and slimes being subjected to washings and siftings with various circular and percussive movements. Sometimes, where other metals of considerable weight are combined with the tin, it is necessary to roast the partly dressed ore, and then again to repeat the washing, and the tin when smelted needs subsequent refinings. Stream tin is generally much freer from deleterious metals than mine tin, and not only costs less to dress, but it commands a higher price, as purity is of great importance in most of the uses to which the metal is applied.

Variations in value.

Thus there is generally a difference of £2 to £4 per ton between Banca and Cornish tin, the latter not being so suitable for coating tin plates. But in times of speculation, when there may be an artificial scarcity of one kind, wider differences occur in the current prices.

Tin oxides sold by units.
See page 438.

The oxide is sold at a price per unit according to its richness. Thus oxide containing 70 per cent. of tin sold at 20*s.* per unit would be worth £70 per ton, or if at 22*s.* per unit, £77 per ton.

Tin standard in Cornwall.

An official price or *Tin Standard* is established every month in Cornwall. This standard is the amount paid to the miner by the smelter per hundredweight of metal contained in the ore as calculated from the results of a dry assay after deduction of 1¼ from the produce per 20 units (6¼ per cent.) for reburning charges. By an old trade custom there is also a deduction on the weight of the parcel of tin ore of 3 lb. per cwt. It is customary to reckon the price by the nearest eighth of a £ above or below the calculated price.

Price of Banca tin.

In the London metal market the price current for Banca tin was long the standard for foreign tin, and Cornish tin is divided into *common*, *superior* and *refined*. But since 1890 tin is designated Australian, Straits, English, or otherwise.

Tin mining is speculative until the mines have been well prospected and the position and richness of the deposits proved sufficiently in advance to justify the establishment of powerful plant. The degree of richness which will repay the getting and dressing, obviously depends on the cost of these operations. After the expense of excavation and getting have been defrayed, a constant and sufficient supply of water for dressing the ore is required, and if the water is not only abundant but has a fall or gravity force, it can be used also as power. It is in this way that some of the tin mines in Cornwall and Devonshire, too poor to allow the cost of steam power when the value of tin had fallen as just described, continued to be worked. Ore containing as little as one per cent. of tin has in favourable cases left a slight profit in the current expenses of working, but has afforded no interest on sunk capital. Some of the most remunerative mines have been those where the original capitalists have abandoned or sold cheaply the plant, workings and other results of their expenditure, so that the new comers have little or nothing to pay beyond the daily working expenses and the repairs of the machinery. Tin mining will sometimes repay those who are content with small wages, where it is quite unremunerative to ordinary enterprise. The Chinese workers in the Malay Peninsula and in Australia, like their countrymen in the gold districts of California, thus continue after Europeans have ceased working; and as the Chinese masters generally make a profit on the provisions sold to their workmen, Europeans who do not adopt this truck system may fail even when they are paying the same low wages.

Tin mining speculative.

Water supply.

Capital lost or written off.

Chinese miners.

Truck system.

Calculations of profit and loss obviously depend on the current price of tin, and the mining industry of a district flourishes or fails accordingly. Thus in Cornwall many of the mines formerly worked at a profit, and which afterwards ceased working, remain still unexhausted till cheaper modes of working or improved prices again allow of profit.

Profits depend on current prices.

GEM-MINING, or the winning of precious stones, may be broadly classed under two heads :—

Gem-mining classified.

(*a*) Where the stones have to be quarried or mined for in the ordinary sense of the term.

(*b*) Where the stones are found on or near the surface in deposits of alluvial gravel generally with considerable admixture of clay, and where, after the actual operations of mining, the labour of securing them consists, first in washing off the clay and lighter portions of the gravel, and then in picking over the remainder for the few precious stones it may contain.

There are few gems which cannot by their occasional occurrence be said to come under both the above headings, but the following classification may still be deemed broadly correct for the purposes of the miner.

Diamonds in South Africa.

In ancient geysers.

Under the first head (*a*) may be classed the Diamond as found, and found only, in South Africa. A typical South African Diamond-mine consists of a more or less circular "pipe," which probably once formed the vent or crater of an ancient mud geyser. These geysers seem to have punched their way up from below through the overlying quartzites, shales and other rocks, and after spouting over the surface, to have become inactive, leaving these pipes thus filled with mud. In course of ages the surface has been denuded, leaving little or no indication of volcanic action, and the mud contents of the pipe have become indurated and otherwise altered into a solid mass of brecciated rock, now hard enough to necessitate blasting to break it out, and locally known as the "blue." Such are the celebrated Diamond-mines of Kimberley, De Beers, and others well known in Cape Colony and the Orange Free State, and it is in the "blue," with its upper stratum of "yellow" ground, but never in the surrounding rocks, locally termed the "reef," that the diamonds are found. In the earlier stages, and in the softer yellow ground, these pipes are mined "open cast," but as depth increases the reef falls in, and shafts have to be sunk in the solid surrounding rocks, from which headings are driven into the "blue" at various levels below. The 1897 report of the De Beers Company gives the depth of the workings, both at Kimberley and De Beers mines, as 1200 feet. Great quantities of garnets, as well as zircons and some other stones, are found with the diamonds, but they have no commercial value. The "blue" ground when first raised to the surface is spread out on weathering grounds, known as "depositing floors," where, by occasional watering and the action of sun and air, it gradually decrepitates, and after the lapse of some months becomes fit to send to the washers.

Kimberley.

Depth of blue.

Depositing floors.

Emeralds.

Opals.

The Emerald, which comes under class (*a*), occurs generally in pockets in hard limestones, and has to be mined for; and Turquoise is won in much the same manner in the form of nodules. Veins of Turquoise are occasionally found. The Opal also, being a vein stone, is to be sharply distinguished from other precious stones which are found as individual crystals. It occurs in this manner in some surrounding rock, which has to be quarried, the thin veins of "precious opal" being afterwards broken out of the fragments.

Indian and Brazilian gems.

Ruby, sapphire, amethyst.

Burma, Siam, Ceylon.

Gold with diamonds.

(*b*) Under the second category comes the Diamond as found in the older mines of India and Brazil, and in later years in Australia and a few other places. Notably also the entire corundum group, the Ruby, Sapphire, oriental Amethyst and oriental Emerald. To it may be added the Spinel and Balas-ruby, the Cat's-eye, Garnet, Zircon, Topaz, Tourmaline, and others. These are found amid the débris of what were once no doubt beds of compact rock long since denuded, their constituent minerals having been washed down, forming beds of gem-bearing gravels in valleys far below their old positions. Such are the Ruby and Sapphire-mines of Burma, Siam, Kashmere and Ceylon, in most of which the less valuable of so-called coarse gems mentioned above are also found. Such, too, are the Ruby and Sapphire-mines of North America, and the Diamond-mines of Brazil and Australia. Stones of the Emerald class are also found in alluvium, but, being comparatively soft, they suffer severely from the grinding action to which they are subjected, and seldom survive to any important extent. Gold is frequently found in paying quantities in gem-bearing alluvials, and should always be sought for.

Machine processes.

Theft of diamonds.

How prevented.

Hand labour avoided.

Not until the development of the Diamond-mines of South Africa was engineering skill applied on any considerable scale to the systematic winning of precious gems. In these mines, though there has been large outlay on plant and machinery for the ordinary mining operations of excavating, pumping, winding, hauling and breaking up the blue ground, much still remains to be done in the direction of eliminating hand labour, and therefore the opportunities for theft at the various stages of the work. By extraordinary legislation and elaborate systems of search rigorously enforced, much has been done in South Africa to check theft on the one hand, and still more so on the other to render the task of disposing of stolen diamonds difficult, but in alluvial gem-mining, where the deposits are spread over large tracts of open country, such methods are of little avail. Unless machinery is employed which may be relied on to extract the gems with little intervention of hand labour, this class of mining must remain, as it has done hitherto, in the hands of natives working in a small way only and with the most primitive appliances. The winning of precious stones differs from every other kind of mining enterprise in that the prize sought for is of such small bulk and such immense value in comparison to its bulk as to render it essential to success that there should be no loss, since the theft of a few stones only may determine the success or failure of large enterprises. Losses by peculation occur even in gold mining, where the precious metal is generally finely disseminated through the gravel or reef and there is little opportunity for theft, as the actual dressing and concentration are performed in machines to which a few trustworthy persons only need have access. Still the loss of a few nuggets or a little amalgam, while reducing the profits of a gold-mine to a small extent, does not materially do so. In mining for Gems, on the other hand, the theft of a few stones may involve a loss of many thousands of pounds. Hence, the necessity for the employment of machinery that will prevent such losses.

Concentration by machinery.

Specific gravity of gems much less than gold.

The high specific gravity of gold, approximating as it does to 8 to 1 of the reef or gravel, and thus rendering mechanical separation of the two easy, is wanting in precious stones, where the difference is seldom more and often less than as 4 is to 3. Ingenious devices for the utilisation of this small difference of specific gravity are, however, now available for the separation without handling, of diamonds, rubies or other gems from the valueless gravel with which they are associated. Such gravels, after being washed and screened to free them from clay and fine sand, are graded into suitable sizes and then passed through mechanical separators which deposit the gems they contain in locked receptacles with only a much reduced mixture of worthless minerals. The final selection of the gems from such a close concentrate can be entrusted to a few trustworthy persons, whereas to hand-pick great quantities of concentrates very many would have to be employed.

Failure with deputed labour.

For want of some such process as the above, mining on a large scale by deputed labour has failed even where the success of native workers has proved the existence of gems in payable quantities, and where, in all probability, the application of machine processes, if they had been available, would have increased the percentage of gems secured.

Prospecting for gems.

In prospecting for gems the probabilities of profit must not be measured by the quantity of gems found, as the real average quantity depends on the careful working of a considerable volume of gem-bearing ground. The speculative element in the enterprise lies in the expenses of development on a large scale. It is necessary, however, to ascertain at an early stage the real quality and value of the stones met with, for many, though coming strictly within the category of gem-stones, have little or no marketable value.

Mining machinery.

In the summary description given in the preceding pages of different branches of mining, the methods and Machinery used have been incidentally referred to. Apart altogether from the main elements of success in mining ventures, such as the presence of the mineral and its value when brought to market, mining enterprise depends largely for its success on the proper selection of appliances for working the mines and dealing with the minerals. It is impossible here to deal with so wide a question as the *Machinery of mining*, but some points may be touched on which more or less affect the choice in all cases.

General rules.

Those who are on the spot and are responsible for the working of the mine are presumably best able to decide on the methods required, for a choice based on the mere theories of those at a distance is liable to error. But where not only the choice but the actual designing of machinery is entrusted to a local superintendent, he may fail because he may not be acquainted with what is latest and best for the purpose in view, or because skill in mining operations is not always associated with skill in the designing of machinery. A more frequent cause of error occurs where—though it is desired to take advantage of the knowledge of manufacturers in special kinds of plant—there is a want of accord between those who purchase and those who sell. This arises mainly from the incomplete information sent from one to the other. The following brief classification of mining plant may assist in the proper setting forth of what is wanted, and in regard to all or any of the classes it is desirable to state, for the assistance of those on whom the design or choice depends—

Choice and design.

Misunderstandings.

1. The general *Purpose* in view, whether temporary or permanent, the kinds of mineral sought, and the scope or extent of the scheme. **Purpose.**
2. The *Class* or classes of mining appliances which are wanted amongst those enumerated, I. to VI. on the following pages. **Kind.**
3. The kind of *Workmen* or others to whom the machinery or plant will be entrusted. **Workmen.**
4. *Climatic* reasons for or against particular kinds of material; scarcity or abundance of fuel, water, or labour. **Climate.**
5. The facilities or difficulties of *Transport.* **Transport.**

Classification.

Mining machinery and appliances may be divided into the following classes, in each of which points have to be regarded besides the general ones just enumerated.

Prospecting plant.

I. *Prospecting and Exploring apparatuses* include those for surveying, boring, crushing, and assaying. A survey may be necessary to ascertain and record the position, stratification and dip of rocks and reefs which hold or conceal the mineral; but a survey should also ascertain and delineate the plan and contour of the ground sufficiently to assist a decision regarding roads, trams, railways, or water-courses. A wise expenditure on a survey will often save enormous expense afterwards. It is necessary, in order to choose the most suitable instruments, to obtain beforehand as much geological information as is available concerning the district, the probable stratification of the ground, and the depth to which it is intended to bore. A small set of boring tools and a prospector's hand-crushing machine will then allow of the necessary preliminary investigation.

Surveying instruments.

BORING TOOLS. *See page* 813.

Assaying apparatus.

The selection of *Assaying* apparatus will depend mainly on the kind of mineral and of the rock which holds it, on the thoroughness with which the investigation is to be made, and on the qualifications of the explorer. Generally, preliminary proving only is necessary for prospecting, leaving a more precise quantitative analysis to be made afterwards and elsewhere if required.

Sinking, getting, and hoisting plant.

II. Machinery and Tools for *Sinking*, *Excavating*, *Getting*, and *Hoisting*, are seldom purchased till a preliminary investigation has disclosed the probabilities of obtaining the mineral within a certain moderate range of depth, and the nature of the ground to be encountered. The expense that can be prudently incurred in sinking any one shaft depends a good deal on the general scheme, and on the extent of ground from which it is proposed to bring the mineral and spoil, by galleries, or otherwise, through the one shaft. There is an immense variety of boring tools for dealing not only with various strata, but with the accidents and incidents of boring. Among such tools are improved percussion rock drills (used mainly as adjuncts to explosives), diamond drills and excavating grabs. These and other modern tools are used with or without the older kind of drills worked from derricks. These derricks and other pit-head framing may generally be built at the mine if timber can be obtained, leaving only the ironwork and machinery to be brought from a distance, but there are cases where it is advisable to construct all the framings of iron or steel. If steam power is to be employed, the choice of engine will depend a good deal on whether, as in a small undertaking, it will have

Sinking of shafts. *See page* 359.

Drills. *See page* 816.

Steam engines. *See page* 566.

to be applied to various purposes, such as drilling, winding, pumping, and crushing, or whether separate engines will be employed; while the boilers must be such as can be transported to the mine, and as will suit the fuel and water available. Information on all these points should therefore be furnished to those concerned in supplying the machinery.

Pumps.
See page 613.

III. *Mining and Drainage Pumps*, with their various accessories, are frequently one of the greatest causes of expense in mining operations, and a wise selection of the machinery is of the utmost importance. There is an endless variety of pumps, and only on the fullest information of all the circumstances of the case can a proper choice be made. While the unwatering of a mine is often the cause of anxiety and loss, a supply of water for the steam boilers and for the separation of the mineral may be equally essential to success. The conveyance and storage of water may have to be dealt with. If pipe lines are required, the hydraulic head or pressure must be stated. Ventilating fans are specially needed in collieries.

Tanks and pipes.
See pages 639 *&* 644.

Separating plant.

IV. The machinery and plant for *Dressing* the ore, namely for separating the mineral from the ore or matrix which contains it, is of infinite variety, but may be broadly subdivided into—

(*a*) Machinery for *Screening*, *breaking*, *stamping*, and *grinding*.

(*b*) Apparatus for mechanical *Separation* by the aid of air, water, or mercury.

See page 373.

(*c*) *Chemical* plant, such as for chlorination or for the cyanide process of recovering gold.

(*d*) *Smelting* and refining plant.

Kind of ore.

It is important to give the fullest description of the ore, not only in regard to its probable constituents as disclosed by analysis, but also in regard to its mechanical condition and moisture when brought to the surface, and the extent to which separation is to be carried on at the mine. In this branch of mining operations due accord should be maintained in the number and extent of machines for each stage of the process. It may appear advantageous to do certain work on a large scale, but unless a corresponding supply of ore is kept up from the mine, and sufficient machines for the after processes are available, the superfluity of plant for the one stage may be a considerable cause of loss.

Transport.
See page 352.

V. *Transport*, and its importance in mining operations, has been already referred to, and the cost of providing transport, if it be investigated at the commencement, may be the principal circumstance in determining whether further progress is expedient. Cart-roads, or aerial ropeways, tramways, railways, bridges, tunnels, rolling stock, canals, harbours, landing piers, lighters, and vessels, embrace the great variety of works and apparatus that may have to be dealt with as mining adjuncts. In the mine itself, as well as when the mineral or spoil is brought to the surface, the choice of method depends primarily on the kind of mineral or material to be carried, the quantity in a given time, the distance, the gradients, the means already available and the obstacles that intervene. But before discussing what may be the best, the preliminary question arises as to the permanency or otherwise of the enterprise. The construction of a railway or jetty may obviously allow a saving over existing means of carriage or shipment, but it must be seen how far the saving will repay the capital expenditure in a reasonable time or before the minerals are exhausted.

See RAILWAYS, *page* 57.

See JETTIES, *page* 127.

Workshops.

VI. *Workshops, Houses, and Tools* are among the subsidiary plant required at a mine. The choice of these depends on the extent of the operations as measured by the quantity of mineral dealt with, the number of workmen to be provided for, and on the number and kind of machines and rolling stock which have to be kept in repair. But there is also the question of locality, for if there be easy communication with towns or places where repairs can be effected, it may be only necessary to have a smithy and carpenter's shop at the mines. On the other hand, where the mining plant is very extensive, or where no outside aid can be depended on, a greater variety of tools and plant may have to be provided at the mines for repairs and renewals.

See FACTORIES, *page* 460.

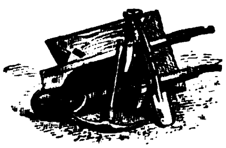
See HOUSES, *Chap. XXX.*

See SMITHY, *page* 771.

See MACHINE TOOLS, *page* 735.

[*See also* CONCESSIONS: THE COMMERCE IN COAL, IRON, AND STEEL: STEAM ENGINES: PUMPS: BORING TOOLS: PIPES: TANKS.]

END OF PART I.



PART II.

CHAPTER XVI.

CONTRACT AND PURCHASE IN THE ENGINEERING TRADES.

Questions arising out of contracts more complex than in ordinary trades.

Intention of this Chapter.

THE questions which arise out of contracts for public works and the various other enterprises which depend upon engineering skill for their achievement, are frequently more complex than those connected with the purchase of ordinary commodities. It is intended in the following pages to classify the principal methods in which purchases and contracts are arranged, and while avoiding purely legal considerations, to draw attention to some of the more important circumstances connected with them, both in regard to transactions completed in the country of purchase and those in which the incidents of export have an important place.

Prices arranged in advance.

Reasons for pre-arrangement.

Comparison of prices.

Bargains have three parts:

1. Agreement to sell.

2. Technical conditions.

It is the almost invariable practice to arrange prices and conditions at the commencement; and although there are certain transactions in which exact pre-arrangement is impossible, the leaving of price or remuneration to be settled after completion occurs now more rarely than formerly. The necessity for such preliminary agreement arises not only from the desire of a purchaser to know how much he will eventually have to pay, but to enable him to choose between competing sellers, whose offers can only be compared by knowing them at the outset. It is evident, however, that mere comparison of prices will not alone allow of a fair judgment between them. Competitive prices must either be based on precisely similar conditions, or the purchaser must be aware of the differences, and have some standard by which to judge. For the present purpose it may be said that bargains for the purchase of commodities or the performance of works have three essential parts: the agreement or contract to sell or buy, technical and other conditions, and measures

3. Measure of price.

of price. The agreement or contract is sometimes merely verbal, more usually by interchanged letters, and sometimes by formal deed. The technical conditions of the commodity or works are described or implied either by

1. Specification or Description furnished by the Buyer. *See page* 413.
2. Specification or Description furnished by the Seller. *See page* 421.
3. Sample. *See page* 425.
4. Reputation or Trade Mark of the Seller. *See page* 427.

The payment or measure of price is either—

a. A Sum of Money. *See page* 430.
b. According to Schedule Rates. *See page* 432.
c. By Units of Contents. *See page* 438.
d. By Results accomplished. *See page* 440.
e. By Measure and Value. *See page* 441.

Contracts made by letter only.

In regard to the first essential—the agreement to sell and buy—a large proportion of British contracts are made in the most simple manner by the interchange of letters, one letter offering to sell certain goods or to carry out certain works for a specified sum of money or other consideration, and a return letter accepting such offer. Or the method may be reversed, the purchaser making an offer and the seller accepting it. Extensive commerce could not be carried on if every transaction needed an elaborate contract document or the intervention of a lawyer; and the simplicity of the British system compares favourably with the formal and tedious contracts adopted on the Continent more often than in Great Britain, and which are apt to repel those unaccustomed to them.

Commerce hindered by elaborate documents.

Formal documents evolved by recurrence.

Formal or legally-drawn documents are usefully applied in the transfer of leading commodities, where transactions of a similar kind continually recur; use and custom having led by a gradual process to the elaboration of forms of contract, or precise clauses, to meet contingencies suggested by past experience. The printed bought-and-sold note of an iron-broker, the charter-party and bill-of-lading of a ship-owner, are instances in point; but in the more frequent transactions, for which there is no exact precedent, such elaboration is wanting, and the essentials being stated, secondary conditions are only implied or understood, leaving to the common law and custom the inferences involved. If such a method of business resulted in vague or ill-defined contracts, it could not be justified, and engineers or others whose duty it is to draw up agreements should, unless they have good precedents to guide them or accumulated

Instances.

Common law and custom.

experience of their own, be assisted by legal advisers. But those who are accustomed to the commerce of the engineering trades are generally able to put into a binding and explicit form the bargain they have made; the sufficiency of such forms would appear to be proved by their frequent adoption, and by the small proportion of them that are the subject of after litigation.

Simple methods proved sufficient.

For undertakings of large extent, or which are likely to be protracted, it is endeavoured usually, by great care and consideration at the outset, to avoid after-disputes; but in all contracts, large or small, care should be taken to set forth all the essential conditions, to avoid ambiguity, and to make the documents—letters, or more formal agreements, as the case may be—explicit and self-contained. But letters make a satisfactory contract only when complete in this simple form; not so when the terms of agreement are distributed through numerous letters or a protracted correspondence. If at the time of agreement the usage in previous transactions qualify or extend the apparent meaning of written conditions, such elucidation should, if possible, be added or embodied in writing while all are agreed, or at any rate the words "as customary" be employed. If in previous transactions between the same party a custom has been established, such a phrase may serve, but if a common "custom of the trade" is meant, then it will be binding only on proof that it is universally adopted and acted on in the trade. Accuracy in stipulations of this kind is especially necessary where the two parties to a contract are not equally informed as to the usage, or are doing business together for the first time.

Care at outset.

Ambiguity to be avoided.

Or too many letters.

Verbal qualifications.

See also page 427.

The agreement to sell and buy is conveniently kept distinct from the detailed conditions; and just as a short form of tender and still shorter acceptance of it may refer to the most elaborate specification, and also even where, instead of such a simple arrangement, formal contract-deeds bind buyer and seller to a bargain, it is usual and convenient that the specification of technical conditions should be kept distinct. But a contrary custom often prevails, and the general conditions or framework of a contract are mixed up with the descriptive particulars which more properly pertain to a specification. This method prevails oftenest when the conditions are stated according to the first method in the category on page 412.

Agreement separate from specification.

Contrary method.

(1) *A Specification or Description furnished by the Buyer* may be said to imply that the buyer knows what he wants and describes it; leaving the seller no choice but to supply what is so described. A specification may, however, be limited to a description of a purpose in view

Specification furnished by buyer may describe purpose or result only.

or results to be obtained, leaving the seller either free scope in the manner of performing it, or necessitating on his part also a specification to show what is intended, and to allow a choice between competing sellers. So far as a buyer specifies his wants, he relieves a seller of responsibility in the choice, unless the contrary be explicitly declared. A specification may consist only of a brief description, or a drawing, or a mere sketch; but if such be the basis of a contract, it will—so far as it goes—declare where the responsibility rests. There are two well-known kinds of contract—first, a customer might ask a manufacturer to make a machine according to a given plan, or according to a plan supplied by the customer; in that case the manufacturer would only have to make the machine according to the plan and in a workmanlike manner. Secondly, a customer might ask the manufacturer to make a machine for a particular purpose, not supplying any plan, but leaving it to him to make it for that purpose; in that case, unless the contrary was expressly stated in the contract, the manufacturer would have to make a machine fit for that purpose. Further, if a manufacturer undertake to supply a machine of his own designing as capable of doing certain work, he is not relieved from responsibility, if it fails to do the work, because the buyer has ordered alterations not considered desirable by the seller, unless the seller objects to them at the time and refuses to make them unless relieved from his responsibility. A buyer sometimes seeks, but improperly, to decide himself upon the method and yet to lay the responsibility on the seller. Thus, an engineer may design a bridge, and may make the manufacturer not only responsible for following the drawings and giving materials and workmanship of prescribed kinds, but, in addition, he may stipulate that the bridge shall, under a certain test load, only bend to a specified amount, or that one span of the bridge, if it be tested to destruction, shall break only with a certain load. Or a steam engine of certain dimensions may be designed by the purchaser or his engineer, and a certain working pressure and speed prescribed by him, and the manufacturer be called upon to warrant an effective horse-power of a certain amount. A manufacturer who accepts such liability may be bound to it, but in such a case he has pledged not only his ability as a manufacturer, but his own skill as an engineer to verify the calculations of the designer. If, without attempting to verify the calculations, he rests content on his belief in the ability of the purchaser's engineer, and the bridge or engine fail to reach the specified test—not through any defect of

Responsibility allotted.

Undue risks imposed on seller.

Instances.

Such liabilities inexpedient.

manufacture, but because the methods and the results are shown to be irreconcilable—the manufacturer will have to bear the loss. Probably, however, in such a case, the terms in which he contracted would have to be very strictly weighed before such unwisely assumed responsibility would be enforced by a legal tribunal.

And of doubtful force.

In a specification of the buyer, it is generally inexpedient to describe the details of workmanship or the methods to be therein pursued, unless on the basis of a full knowledge of the subject; for the mistakes or discrepancies which are likely to result will afford room for disputes and evasions. It is much better in such a case to describe as clearly as possible the ultimate object in view, and only in general terms the quality that is desired, thus putting upon the contractor the responsibility of doing what is evidently demanded. The force of such general terms is weakened by adding detailed instructions, unless the latter be very complete, because their presence in regard to some parts implies that the contractor is to look to the specification for instructions, and that, where absent, no particular methods are desired. But there are cases where the opposite plan is preferable. Thus, there may be some article which can only be tested by long use, and any composition or method of manufacture which has proved best in the past may be prescribed with advantage. The alloy for an engine-shaft bearing, or the brand of iron for a boiler is sometimes specified with much minuteness where seemingly more important details or conditions are left to the manufacturer.

Buyer should not prescribe methods.

But results only.

Opposite plan sometimes expedient.

Instances.

The advantage to the buyer of affording a full knowledge to the seller of what he will be called upon to do under an anticipated contract is so well understood by those experienced in such transactions, that much trouble and expense are frequently bestowed on the calculations beforehand of the scope or extent of a coming undertaking. Buyers do not always recognise what is involved in the omission of such an investigation, or the putting the burden of it on the seller. Particulars presented to manufacturers or contractors upon which to frame their tenders may be insufficient in the sense that they are vague or incomplete, or in another sense, that while full and elaborate, they are so voluminous as to be difficult of computation. As an example of the first kind, if a buyer ask for a steam-engine of a certain power, and omit to state whether it is to include a boiler, or at what pressure it is required to work, or how its power is to be computed; or if a bridge of a certain span be required, and no width of roadway or amount of load be stated, the various prices which

Buyer should afford full knowledge of his wants.

Particulars often insufficient.

Instances of vagueness.

See pages 53 *&* 457.

Prices on such basis inconclusive. different manufacturers under such a specification may offer will of themselves afford no true basis for comparison. Indeed, were it not the case so often that those not technically informed do present a meagre specification, and act upon prices unaccompanied by a full specification of the seller, the fallacy of such a method would appear too obvious to be mentioned. **For lowest offer may imply low quality.** For of such prices, the lowest will probably come, not from the manufacturer who will do what is really wanted most cheaply, but from him who has interpreted most lightly the duties involved, or who will venture—in good faith possibly—on the lowest margin of strength and safety in the structure. The knowledge among competitors of this inconclusive method of comparison tends to degrade the quality of commodities. **Specification from seller then necessary.** A comparison of offers based on an insufficient specification of the buyer can only then be made by requiring with each price a description of what it is intended to supply; *See pages 421 & 427.* and this method of contract involves certain contingencies which will be presently described under the head of Specification of the Seller. It is very difficult in the case of certain commodities to apply a standard of quality. Thus, in the purchase of iron or chemicals, the real value may be ascertainable only by elaborate tests or analysis, and purchase by sample or by units of contents becomes expedient. *See pages 425 & 438.*

Particulars varied or voluminous. In the second case referred to above, the particulars presented to manufacturers may be insufficient, because the drawings and description of works are so varied and voluminous as to involve great trouble and expense in calculating the value of what they represent. **Calculation of quantities.** The first step in making an estimate of cost is to reckon up the quantities of material and labour required. In simple matters, each competitor may be left to calculate these items: for instance, in the purchase of a steam engine or a lathe, there is no need to tell the seller the number and dimensions of the various pieces in the machine, or its weight. **Sometimes left to seller.** And, in regard to larger and more complicated works, the purchaser may deem it best to leave each competitor to calculate in his own way the cost of the undertaking. **Seller may prefer it.** Indeed, the skill and experience which enable one contractor to estimate, more correctly than another, the cost of works, is a distinct advantage which he may desire to retain; and, if the competition be limited to a few, he may prefer to take the trouble which such calculations involve, rather than have facilities granted to all. **Not advantageous to purchaser.** But it is questionable if it is to the advantage of the purchaser to limit the competition to the few who are able to calculate the quantities of works, for ability to carry them out may be more widely found. And, if numerous tenders are invited, even experienced contractors may be unwilling to make troublesome estimates where the chance of success is but small. On the other hand, there are certain undertakings in which the cost will depend mainly on the methods pursued, and where there is no difficulty in calculating the quantities. But to calculate from drawings and description the quantities of some important work like a railway, a harbour, or a bridge, is often a protracted and expensive operation; and not only is much waste of time and money involved by putting the burden of this on each competitor when it might be done once for all, but there is the probability that the apparently most favourable tender will come, not from the contractor willing to work most cheaply, but from one who has arrived at the lowest measurement. It is customary, therefore, in important undertakings, for the buyer to calculate the quantities and to furnish a list of them to the competitors, so that each may form an estimate on a similar basis. So much does the custom of calculating the quantities beforehand prevail in certain trades, such as the building trades, that a separate profession, that of "Quantity Surveyor," has arisen in London and other large cities to satisfy the demand, and "bills of quantities," calculated by able and impartial surveyors, are accepted by buyer and seller alike as the basis of a contract. Quantities so furnished serve as a useful check on the drawings, and allow a buyer to verify, more easily than he otherwise could do, that he has obtained all that he bargained for; for where quantities have not been agreed upon, opportunities for evasion are more frequent. Thus, in the case of a large bridge, or roof, or other structure of iron, it is difficult to measure exactly the thickness of the various parts, and a manufacturer whose price might be two per cent. the lowest, might perhaps supply five per cent. less weight than a skilled surveyor would have calculated from the drawings. A previous agreement on the weight to be supplied removes this risk; and, moreover, the relation of price to quantity affords a convenient standard for measuring the value of additions or omissions. Payments based upon schedule will be presently alluded to. A bill of quantities is particularly necessary when one set of drawings serves for more than one contract, as without such a definition disputes may arise as to which of two contractors is to execute certain work.

Contractors may be unwilling to tender.

Elaborate quantities.

Reckoned differently.

Unless computed once for all.

Quantity surveyors.

Bills of quantities.

Advantages which they afford.

See page 432.

In defining extent of contract.

Simplicity in the form of contract is most usual in cases where buyer and seller are equally well informed and come into immediate

Formal contracts often one-sided.

Buyer should offer equitable conditions.

contact and agreement. The more formal or elaborate contract documents often have the characteristic—in which they differ from almost all other commercial agreements—that they are drawn up entirely on one side, and are not arrived at in the usual way by discussion between the parties concerned, and by that modification of clauses which different points of view suggest. Such a preliminary discussion being obviously inconvenient and almost impossible in the multifarious cases where contracts for the supply of commodities or the carrying out of works are presented for competition, it would appear desirable for the buyer, instead of looking from one point of view only, as might be justifiable where modification from the other side were to follow, to prepare such equitable conditions as should at once command the confidence of the contractor.

Buyer's obligations not defined.

Left to inference only.

Certificates. *See page* 24.

Certainty and precision best basis for contract.

Even in the best of contracts, drawn up in the interests of a buyer, the obligations of the seller will generally be much more strictly defined than the return obligations of the buyer, who often has duties not confined merely to certain payments of money. Questions which may arise out of these points will have to be decided on inferences drawn from the general tenour of the contract, and such uncertainty, if carried too far, is unsatisfactory to both sides. As instances, a seller may be bound to deliver, but a buyer may not in terms be bound to receive, or to send the inspector whose certificate is preliminary to reception; and being thus unready, may be unwilling to pay. Or, in the carrying out of works, the employer may fail to have the site ready at the proper time or to provide right-of-way to it, and as these obligations are not referred to in the contract, it is by implication only, and as a condition-precedent to be inferred, that a seller can obtain compensation. Certainty and precision are the best bases for a contract, and if those who, unopposed, have the formulating of an agreement, make it one-sided or unduly stringent, it is against the true interests of the buyer for whom they act.

Price enhanced by uncertainty.

Cost may depend on action of engineer.

As has just been seen, an exact estimate of cost is only possible where the commodities to be supplied or the services to be rendered can be exactly measured; and if there be doubt as to what may be demanded, an addition is made to the estimate by way of insurance premium against contingencies. In contracts for public works, the engineer frequently takes power to make certain modifications as the work proceeds, or important details are left to be carried out as "the engineer may direct;" but unless this latitude be strictly defined, or corresponding alterations in price arranged, uncertainty will hinder a

Reasonable latitude.

Unfair preference.

Modifications provided for.

Good contractors averse to doubtful risks.

proper estimate of cost; and the worst of all risks is one depending on the action of another person whose motives are unknown. If, however, it is only intended, and is so expressed, that the contractor may be called upon to obey details which, though propounded after the contract is signed, shall be such as may be reasonably inferred from the contract drawings and specification, such a condition may be accepted as fair. Uncertainty of this sort may, however, lead to absolute unfairness; for if a favoured contractor has interpreted to him the real intention of clauses (which without such explanation have wide limits), he can measure more exactly than his competitors, the cost of the undertaking. It is worth much trouble to prescribe everything at the commencement, and where this is impossible, modifications in regard to works or material should be provided for by schedules of rates or prices, so arranged as to allow easy analysis or comparison. Contractors who have much to lose, and who, therefore, are presumably best fitted to carry out a contract, hesitate to engage in one which they cannot measure; or if they venture, they do so only at an enhanced rate. Tenders without such enhancement are made only by those who are ignorant of the risks, and therefore ill-fitted for the work; or by those who are willing to speculate or gamble in unknown risks.

Jurisdiction.
See pages 24, 54, & 243.

See page 54.

See page 43.

Law evaded by one-sided conditions.

Assuming that the extent of works or services to be performed or commodities to be supplied is so defined as to allow appraisement, there still remains as a point of great importance, the jurisdiction under which the contract is to be carried on or by which possible disputes must be settled. Strong and impartial tribunals in all countries which possess them, afford great encouragement to commerce, for exact calculation, expenditure, and profit can be made only when all risk of confiscation is removed; and the certainty so induced allows, in the competition of traders, a cheapness in price which is to the general advantage of the community. When such confidence is wanting, and where the rights of either side are insecure, public works are neglected and commercial enterprise of all kinds checked. It is for this reason that many contractors are unwilling to undertake works abroad that may be subject to foreign jurisdiction. But very often the insecurity arises even where the laws are just, because by the terms of the agreement some other and outside tribunal is substituted. It is in contracts based on a specification of the buyer that such cases arise, because of the opportunities afforded of making one-sided and inequitable conditions.

Litigation.
Arbitration.
Favoured by the courts.
Choice of arbitrator.
Standard form of agreement.
Buyer's engineer as arbitrator.

Litigation on technical matters is in all countries tedious and expensive, and there has been among trading communities a tendency to provide against litigation by a reference of disputes to arbitration; and the tendency has, in Great Britain, been encouraged by the practice of judges to refer cases from their courts, and by direct legislative enactments making arbitration awards binding. Indeed, in some cases, the habit of the judges to refer cases to arbitration has outstripped public opinion, and litigants desiring the decision of a judge or jury, have been thrust back on a tribunal little or no less tedious and expensive, and whose decisions are less authoritative as precedents. The appointment of an able or impartial arbitrator is obviously a matter of the first importance, and if he be not named in the contract, it is usual to specify the method of choosing one. Among architects and builders in London, the necessity for conditions fair to both sides led even to the drawing up of a set form of agreement, which is frequently adopted as a basis for contracts; the conditions of the building trades in London, the relation of client, architect, and builder peculiar to England, and the general similarity of the undertakings in question, having rendered such a standard form possible. Some such method would be preferable to the custom which frequently prevails of appointing, as a condition of the contract, the buyer's engineer as arbitrator without appeal, a practice often inequitable, though possibly convenient.

Origin of this stipulation.
Engineer judge in his own cause.
Arbitrator not independent.

Engineers who have the conduct of important works, and who, perhaps, have had unpleasant experience of past disputes, demand such a condition, because it gives them full power over a contractor; and it is because the engineers who have inaugurated this system are men of eminence and position, into whose power contractors have been willing to place themselves, that so bold an innovation has prevailed at all. But cases often occur where such a condition is unfair, for points in dispute may arise from some act of the engineer himself, who is thus made judge in his own cause. The courts scan very rigidly such powers given to an engineer, and when constrained to enforce them are apt to deprecate strongly the custom which leads contractors to give up their common-law rights, especially when such powers have been claimed and made a condition of contract by engineers who are salaried servants, or who in some other way have not the independent position which might in particular cases justify such power.

The desirability of encouraging contractors to compete whom such risks repel, and the obvious advantage of giving that confidence and certainty of justice which bes[illegible]nduces low prices, and in deference also to the expressed opinions of the judges, this custom has been abandoned by most State departments, and equitable arbitration conditions are provided.

This system abandoned by State departments.

Contracts based on specification of the seller.

(2) *The Specification of the Seller* is made the basis of a contract most often when the commodity sold is one of an accustomed kind, or is a specialty of the seller, or is one in which, for these or other reasons, he is independent of outside skill in design. The use of this method of contract does not, however, entirely depend on such considerations, but in England arises from various other causes. The functions of the professional engineer are kept more distinct from those of the manufacturer or contractor in respect of some branches than of others; and while, in railways, harbours and the works arising out of such undertakings, the civil engineer generally presents a complete design to the contractor, in other and more purely mechanical works a specification of the seller is invited. Thus, while on the one hand, for works involving operations with land, docks, bridges, buildings, the making of the design is a separate function, on the other hand, the designing of steam engines and machines is generally left to the manufacturer. The habit of specifying only the purpose in view or the result to be obtained, and inviting the manufacturer to propose his own method of doing it, prevails more frequently in the United States than in England. In America there is not the same line of demarcation between the professional and manufacturing engineer, and no etiquette forbids the combination of the highest skill in public works with the commercial enterprise of the trader. Thus, an engineer-contractor will propose his own method of constructing or improving a harbour, of making a railway, or supplying a town with water, and the condition that payment shall depend on success induces confidence in the offer; or a railway company requiring a bridge may furnish to numerous manufacturers certain particulars in regard to site, span, rolling load and limit of stress; or, in the case of a locomotive, the load to be hauled, the gradients and other essential particulars; and then each manufacturer is invited to submit with his tender his plan or specification. This method, while implying considerable enterprise on the part of the contractor, and his willingness to incur preliminary expense with a view to after profit, has the great advantage to the purchaser of eliciting the ideas of numerous designers. Moreover, it allows

Reasons for this method.

Design left to manufacturer.

Prevails more in the United States.

Engineer-contractor.

Payment depending on success.

Instances.

See also page 440.

Advantage to purchaser.

economy in execution, because contractors or manufacturers are encouraged to employ the highest engineering skill; and being thus allowed to work in their own way, can venture on special tools or preparations, or can keep suitable material or even finished parts in stock. Where, however, by the custom of the trade, every buyer presents some new idea or design for execution, no such preliminary saving can be effected.

Promotes cheapness.

Skill needed to compare offers.

Although it may appear easier to the buyer to appreciate and criticise the designs of the seller than to originate similar designs, skill and discrimination are needed to measure and compare the respective merits of numerous offers propounded according to different specifications, which depend upon technical details. Frequently the terms of such specifications afford an insufficient basis of comparison, and the decision has to be guided by the apparent or known ability of the various competitors, or by their conduct in previous affairs. In so far as such considerations prevail, they bring the transactions into the category, presently to be described, of purchases based on the reputation of the seller. The skill which may be required to distinguish between competing offers may also have to be applied to the inspection of the work during or after execution; for though the specification may be that of the seller, the due fulfilment of it has as much to be insured as though the conditions had originated with the buyer.

Difficulties.

Choice guided by reputation of seller.

See page 427.

Manufacturers averse to giving information.

See also page 424.

The specification of a seller often affords valuable information, especially if the description includes drawings or designs; and the best manufacturers are often averse to supplying such information except when assured of fair play. Where it is intended by the purchaser or his agent to buy from a particular seller, and other offers are asked for, either to give the semblance of competition or to elicit prices which can then be offered to the favoured seller, such a course of action is uncandid and unfair. In some cases the estimate or tender of an experienced contractor is, as an assurance that certain works can be performed for a specified sum, of as great value to a purchaser or a rival contractor as a design or any other essential part of an undertaking. And when the purpose is to elicit not only prices, but technical information and designs, with no intention of paying for them or purchasing the things or works they represent, the transaction is very much like one of obtaining value by false pretences.

An estimate of cost often valuable.

Designs unfairly obtained.

Specification of seller one-sided.

The specification of a seller is often as one-sided as that of a purchaser, for, like it, it is drawn up in the interests of only one of

And deficient.

Seller's responsibility.

See also page 414.

How inferred.

the parties concerned. All the merits of the article in question are probably set forth, but suggestions which will enable the purchaser to see its unsuitability for particular purposes and to choose what is better or more suitable are too seldom given. The specification of a seller is sometimes that given in a printed catalogue or price-list, where it may consist only of a brief description or even of a mere picture. But even though the specification be of this meagre kind, the seller is not relieved from responsibility. The article sold must be reasonably fit for its specified purpose. More than this: where a manufacturer, or dealer, or contractor, agrees to supply an article which he is accustomed to manufacture or sell, to be applied to a particular purpose described to him by the buyer, who thereby trusts to the seller's skill and judgment, it may be reasonably inferred that the article sold must be fit and suitable for the purpose in view; and the responsibility for such fitness will rest with the seller.

Trade catalogues useful.

Factors.

Aid of engineer to select or verify.

Abuse of catalogues.

Choice from catalogues difficult.

See page 766.

Purchasers are greatly assisted by catalogues of manufacturers or merchants, and indeed, the commerce of certain trades could not be carried on without them, especially in foreign countries, where purchasers have no other immediate access to the seller. Although, in the case of important commodities, the catalogue of a manufacturer may be preferred, there are some trades in which the interposition of a factor is almost essential. Thus, in the case of hardware, tools and other minor articles, the actual manufacture of such varied articles is so divided as to render most tedious the collection of each from its separate maker by a purchaser, who finds he can obtain what he desires better and more cheaply from a factor of repute, accustomed to the trades in question. Sometimes the intervention of an engineer, technically acquainted with the articles required, is necessary to select or verify the purchases. For the catalogue system may be abused, and there are some so-called manufacturers whose stock-in-trade is nothing but a catalogue, and who tempt purchasers by offering inferior goods at apparently low prices. The engravings may be well executed, and there may be nothing by which a purchaser or merchant can detect the truth, for the qualities which really determine the comparative value of two articles apparently similar are not easily discernible by the uninitiated, to whom it may appear a mere waste of money to pay the higher price. The suitability of the design, the proportion of the parts, the quality of material, and the accuracy of the workmanship, determine the fitness and durability of a machine for the desired purpose.

Catalogues impossible in certain trades.

But while, in the case of machines, apparatus, or material, which are of an accustomed kind, and which may be enumerated in a list, catalogues are easily compiled, there are, on the other hand, many—and among them the most important—of the trades connected with engineering, where precise catalogues are impossible because of the ever-varying nature of the commodities manufactured. Thus there are factories where steam-engines, mill machinery, electrical appliances, or hydraulic apparatus are made, and in which every case as it arises differs from all that have gone before it. So also in the case of structural steelwork, manufacturers of ships, bridges and roofs find it almost impossible to compile a price list, because the same combination of dimensions or conditions is never repeated, and structures must be contrived to meet each case. Manufacturers may, however, in such cases furnish the types they are prepared to offer, or the style of design, which can be adopted to the particular case in view. Many manufacturers of repute are for other reasons averse to printing catalogues. They stand upon their reputation, and are unwilling to publish drawings and prices which will be compared with those of rival or inferior manufacturers by persons who are unable to discriminate between them, or who may use the information to the disadvantage of the seller. But in both the cases mentioned above—namely, in that where, from the nature of the goods, catalogues are impossible; and in the latter, where disinclination rather than difficulty is the cause—much might be done to meet the convenience of purchasers and at the same time promote the interests of the seller. Many transactions which might be advantageous to both sides are hampered or get into wrong hands, because the purchaser has nothing to assist his choice, and does not know where to look for guidance. If, therefore, manufacturers who are unable or unwilling to publish catalogues could give directions to purchasers how to approach them, they would by that alone confer a great service. They need not furnish drawings, they need not even give an inkling of prices, but they could inform a would-be purchaser what particulars he must furnish to allow a proper choice, and what conditions of purpose or durability will determine price; in fact, explain what preliminary steps are necessary to enable those who wish to buy, but who are ignorant, to approach those who wish to sell and are well-informed. The position and probable knowledge of the purchaser should guide the seller in the information he supplies. But in regard to particulars of this kind, and indeed generally to

Instances.

See ELECTRICITY, BRIDGES, ROOFS.

Some makers averse to catalogues.

Other aids to purchase.

Seller may assist choice.

Preliminary trouble asked or offered.

According to briskness of trade.

specifications from the seller, the condition of trade at the particular time does much to determine the willingness of manufacturers or contractors to afford information; and while, on the one hand, traders may, in prosperous or busy times, decline with too much independence all preliminary trouble, so, on the other hand, purchasers are apt to take advantage of dull times to demand from traders the gratuitous supply of designs, prices and preliminary information of great value.

Purchase based on sample.

Sellers' samples afford wide choice and low prices.

New samples cheaply worked to for large quantities.

See ROLLING STOCK, *page* 711.

See also page 434.

(3) *Sample* is not only frequently made the basis of a contract to purchase, but occasionally also of contracts for the carrying out of works. Sometimes the sample is provided by the purchaser, who offers thus a common standard for all competitors, while sometimes each separate offer is based on a sample of its own; these two methods bearing the same relation to each other as the specification of the buyer and that of the seller already described. The purchaser, by allowing the sellers to furnish their own samples, has a wider choice than if a fixed standard was prescribed, and presumably, at the lower prices which a manufacturer or dealer will offer for an accustomed design or quality. If the object of the purchaser be to obtain a choice of numerous kinds, the system of separate samples may be preferable; but if the latitude is merely to elicit low prices from manufacturers, it will generally be found effective only for contracts of small amount; for in large contracts which will repay the cost of special preparations, manufacturers will generally be ready to work as cheaply to a sample of the buyer as to their own. For instance, on a railway of considerable extent, an engineer will generally demand exact conformity to a standard sample for the smallest detail of equipment; while if material only for one mile of railway be required, the engineer's choice of design might well be guided by what manufacturers had ready-made, or could most readily supply. But in any case cheapness is promoted by conformity to accustomed systems of measurement and price.

Certain qualities best specified by sample.

It is often easier or more convenient to specify various qualities of a commodity by sample than by a written description; and this is especially the case where exact uniformity with something that has gone before is required. Such uniformity may be in colour, form, dimension, or other quality; and may, in any of these respects, demand resemblance so exact as to render the old and new interchangeable. Thus, there may be parts of a machine or apparatus

Where exact conformity is needed.

As in railway equipment.

constantly wearing out, where the new must fit with accuracy the place of the old; or, as in the case of ammunition, where conformity in a new supply to established standards may be absolutely essential. Or, as in the case of railway equipment, where the material of the permanent-way, or certain parts of the rolling stock, must be similar in kind and size throughout, the standard presented for imitation being considered rather as a pattern than as a sample; other qualities than those of form and size being declared by a writtten specification.

Comparison by test or assay.
See pages 350 *&* 438.

Specification and sample combined.
See ROLLED IRON, *pages* 546 *&* 555.

See pages 432 *&* 438.

A comparison of the bulk with a sample often involves tests, assay, or analysis; and where examination in this way is likely to be resorted to, a preliminary agreement as to the various qualities of the sample should be made between buyer and seller, so that the sample itself need not be examined to afford a basis for comparison in these respects, but may remain to serve as a pattern for form, dimension, colour, or workmanship. In some cases, such as that of wrought iron, tests by bending may be specified, and the sample serve to show the amount of bending or distortion to be undergone, while other tests for strength and elasticity may be described in writing. In some cases, absolute conformity to a sample is not demanded, but within certain limits, latitude is permitted and allowed for in the price. Contracts so arranged may then come within the category of Purchase by Schedule, or by Units of Contents, which will presently be described.

Sample as basis for large works.

As in a railway.

See Chaps. XI. and XII.

Where applicable.

Sample is occasionally made the basis of contract for the carrying out of large works. For instance, in the extension of a railway, the line or direction and the levels having been agreed upon, the kind of material, solidity of works, and the amount and quality of equipment are summarily specified as to be equal to those of the existing railway, or of a neighbouring line. So also, in the case of a new gas or electfic lighting undertaking, the contract may briefly enumerate the area to be covered and the number of lamps, and in all else refer to the works of some other town as the standard of quality to be followed. Contracts of this kind may, by their very simplicity, avoid occasions for dispute; but, on the other hand, unless the circumstances be exactly similar to those of the prescribed standard, abundant opportunities for difference will arise for litigious persons. Such a method of contract is most suitable between persons who know each other, who by reason of previous transactions attach the same meaning to words, and above all, who have the intention, mutually appreciated, of carrying out the undertaking fairly.

A buyer by sample is not considered to have accepted goods till he has had a reasonable opportunity for examining and comparing them. If goods be found to contain defects, and it be discovered on examination that the sample has hidden defects of a similar kind unknown to both sides, the seller cannot plead this as a justification for what he has supplied. On the other hand, a buyer cannot claim to have bought by sample merely because, during the negotiations, the seller has exhibited specimens of his wares, and given certain assurances. The law is very strict in requiring evidence of warranty, and without touching here upon legal questions, it may be said that where any order is given in writing, it supersedes all verbal communications that have gone before: and the terms of such written order, rather than of any assurances which preceded or accompanied it, will be considered as the contract. Therefore, if specimens or samples have formed part of the preliminary discussion, and conformity to them is required, such a condition must be clearly set forth in the agreement to purchase, and not be left to inference only. The purpose of the sample in regard to which of its qualities—material, dimensions, or other—conformity is required, should be specified. Where samples have to be taken from considerable quantities as in the case of minerals, skill and experience in sampling are necessary.

Comparison of bulk with sample.
See also page 440.

Hidden defects.

Warranty.

Written contract supersedes verbal assurances.
See page 413.

Purpose of sample must be specified.

See MINING, *page* 350.
See COKE, *page* 536.

(4) The *Reputation* of a manufacturer, contractor, or dealer, may induce such confidence in his ability and fairness, as not only to render the competition of other traders unnecessary, but also to obviate the necessity for a specification of quality. Buyers who have had previous satisfactory dealings with a seller, will continue to purchase from him, and a large proportion of the trade of the country is conducted in this way. The nature of the contract, its quantity or extent, and the real purpose desired by the purchaser having been sufficiently described, the quality of material or workmanship is considered to be sufficiently assured without the minute enumeration in detail of the methods to be followed, or other conditions which generally accompany a specification of the buyer. Or, the seller is invited himself to describe what he will do, and to propose the conditions under which he will work; contracts arranged in this way coming within the category just described, of those based on the

Reputation of the seller the guarantee of quality.

This method often adopted.

Specification avoided.

Seller names his own conditions.

Sometimes also with sample.

Buying from abroad.

See Chap. XVII., EXPORT.

Wider choice sometimes preferable.

specification of the seller. In other cases, the description of kind or quality may be summed up, by the buyer referring to something previously done by the seller, thus in effect basing the contract upon sample and reputation combined. The reputation of the seller is valuable to purchasers who, being concerned more for the proper carrying out of their wishes than for buying on the cheapest terms, buy where they think they will have the least risk; and especially may this be prudent, when business is transacted from a foreign country. It is considered that the trouble of seeking for competitive prices, and the inspecting the work before payment, will more than outweigh the saving in cost that might be obtained. On the other hand, where an existing organisation of engineers, agents, or others is available, advantage may be taken of it to obtain a wider choice: and this is sometimes desirable, not merely for the sake of possible cheapness, but because novel or improved methods and kinds may have arisen.

Trade-mark or brand.

An assurance of origin.

As in the branding of iron.

See ROLLED IRON, *page* 544.

Trade-marks of secret mixtures.

Trade-mark more permanent than patent-right.

The reputation of a maker or dealer is frequently embodied or expressed in a trade-mark or brand, this plan being useful or necessary where the commodities are of a kind which reach the ultimate purchaser or consumer through an intermediary; some mark or sign actually pertaining to the commodity being necessary as an assurance of its origin. The trade-mark is often convenient as expressing the quality of material to be used by the intermediary in some finished article; as, for instance, where an iron bridge or boiler has to be made of certain plates, the trade-mark on each plate will afford lasting evidence, even after the plates have been manipulated and fashioned into the bridge or boiler, which would be wanting if cast iron or brass, not so easy to be branded, were the material in question. Trade-marks are used sometimes to denote the origin of, or property in, certain secret or empirical mixtures which have a supposed value. Thus, there may be a peculiar kind of paint or metal alloy, concerning which an inventor or dealer may wish to associate some name or mark that will identify it as his own monopoly. Or, when placed upon some apparatus or machine whose nature or construction is evident, a trade-mark may give a more permanent monopoly to the maker or dealer than would a patent-right limited to a term of years, because while, after the term expires, the right of manufacture becomes common, the monopoly of the trade-mark will remain. But obviously its value will continue only so long as the seller can induce the belief that his mark or guarantee is the true test of quality, rather than the form or appearance of similarity which may be given by others.

Trade-marks valuable in distant countries.

Trade-marks have their highest value to purchasers in distant countries; and, indeed, some trade-marks which are of importance there, are hardly known at all in the country of manufacture. Rolled iron, galvanised sheets, and steel tools are among the most familiar examples connected with the engineering trades. To the ordinary purchaser, and indeed often even to experts, there is little in the outward appearance to denote quality; and the trade-mark gives an assurance not only of quality but of kind also, so that, even in places remote from the port of arrival, the purchaser may know by reference to the trade-mark that he is getting what he asked for. In the case of certain commodities, such as tools or agricultural implements, the name of the maker is the best of all trade-marks, and if, with the name or appellation, a purchaser states the size or number, so as to identify what he requires, the specification is complete.

Instances.

Renders purchase easy.

Trade-marks impose obligations.

An established trade-mark, while conferring rights on its possessor, involves obligations which justify the protection which the law affords it. The identity of origin which a trade-mark conveys is a pledge of quality given by the seller, whose reputation would suffer by any default; and so well is this understood, that the proprietor of a trade-mark will generally take care to maintain the quality, even if circumstances induce him to sell at a low price. Where cheapness is demanded, the proprietor of a trade-mark may try to meet the case by selling goods "unmarked," i.e. without the trade-mark: but if the trade-mark be insisted on, then, whatever the price, the quality which repute associates with it will be given. Sometimes a manufacturer will have various trade-marks, to denote different kinds or qualities.

Pledge of quality.

Unmarked goods.

One maker having various marks.

Trade-marks of dealers not makers.

Trade-marks do not always belong to a manufacturer, but sometimes to a dealer or merchant, who, buying where he pleases, gives his stamp or guarantee of quality. A trade-mark or brand may, in such circumstances, merely imply "imported by" or "examined by" the owner of the mark; but the buyer is careless of the actual origin of the goods, if it has been proved by experience and expressed in an established reputation, that a certain kind or quality will be found associated with the mark. This kind of trade-mark may be compared to the resale of goods after an auction, where a would-be purchaser, having no confidence in his own knowledge of the goods offered, and who, therefore, abstains from bidding, may be willing to offer an

Why valuable.

advanced price to a well-informed bidder, whose bids, if honestly given, may be considered a guarantee of value.

Abuse of trade-marks.

The system of trade-mark or brand is liable to be abused. The actual falsification of such marks, or the fraudulently placing under cover of real marks, substituted goods, are risks which have been greatly lessened by the international treaties which protect trade-marks in foreign countries. But sometimes a trade-mark, implying really no special quality, may, by persistent assertion, attain a reputation undeservedly high among buyers. On the other hand, where the mark really implies all that is supposed, a buyer at a distance may unnecessarily enhance the price he has to pay, by insisting on one particular brand, while a qualified agent, with some latitude allowed him, might choose between several brands equally good, or by his own knowledge, venture safely to buy unmarked goods. Able engineers often pointedly abstain from specifying trade-marks, and, by insisting only on a prescribed quality, obtain the benefit of an unrestricted competition. In some trades, certain conventional marks which have no real meaning, and which are common to all who choose to employ them, are used, this chiefly occurring in the class of goods exported to ignorant or half-civilised peoples.

Insistance on one brand enhances price.

Some buyers avoid branded goods.

Conventional or common marks.

Referring to the various modes of Payment and measures of price enumerated on page 412.

A sum of money the measure of price.

(*a*) *A Sum of Money* is the most usual and simple measure of price for goods to be supplied or work to be done. The price of a commodity that can be clearly defined—a steam engine, for instance, or a plot of land—is naturally expressed so, and there is no need of any other method; and it is only when the peculiar nature of the contract renders this method inconvenient, that the consideration or payment is stated in some other way. To the purchaser, at any rate, a foreknowledge of the exact sum to be paid is convenient; and it is generally the aim in all kinds of contracts, whatever may be the precise way of arriving at it, to agree as nearly as possible on the price. So much do purchasers generally desire this precision, that even in complicated transactions, where it is difficult to appraise beforehand the costs and charges, a price stated in one sum is preferred, because it may be supposed to save all risk of extra charges, even though some other measure would appear to allow a lower and fairer valuation. A seller or contractor who is asked to tender for

This method sometimes inconvenient.

Foreknowledge of price obtained.

goods or works which, from their diversity, kind, or extent cannot easily be measured in advance, will, on the other hand, offer cheaply only if he is allowed to stipulate for extra payments should certain events arise. If, however, only offers at a fixed price will be entertained by the purchaser, then an addition is made to the price to provide for contingencies—in effect, a premium of insurance against risks. The advantages, however, of knowing from the beginning what is to be paid, often fully justify such a course. As the removal of uncertainty allows a close estimate of cost, contract by a fixed price is facilitated when, by a preliminary calculation of quantity, the extent and nature of the contract are ascertained; and, as has been seen, this investigation is sometimes performed by the buyer and sometimes by the seller. Even with this assistance, the responsibility undertaken by a contractor sometimes involves considerable risk. Thus, the supply of goods or the carrying out of works may be spread over a long period of time, within which there may be great fluctuations in the price of labour and of material, which cannot be altogether met by preliminary agreements or purchases on the part of the contractor. For instance, in railway works, some special cause may drain the neighbourhood of workmen or make labour scarce and dear; or the material to be excavated may prove to be much more difficult than was anticipated. More than this, contractors are sometimes required to include what is not properly within their province, such as the cost of land, the compensation for damage to occupiers, or even the raising of capital on shares. There is the disadvantage to the purchaser, when this system is adopted, that while the contractor reaps all the profit if circumstances prove easier than was anticipated, on the other hand, the burden may prove too heavy if the contingencies are greater, and the contractor may be unable to carry out his engagements. From causes such as these are owing, on the one hand, the large profits accumulated by the fortunate contractors, and on the other hand, the heavy charges which purchasers have had to bear in the transfer of contracts to new hands. Indeed, speculation is sometimes fostered by such a system, and contractors, sanguine as to the profit, may venture on undertakings whose risks may be too great for their means; and the security or sureties which may be demanded by purchasers to provide for such an event may prove insufficient, or at any rate throw the burden of loss on to others. While, however, purchasers may insist on the appraisement beforehand of risks, it is so obviously impossible

Price cheapened if risk removed.

Uncertainty enhances price.

Preliminary calculation of quantities.

See also page 360.

Contractor's risks.

Fluctuations in prices.

See pages 387 & 443.

Works prove difficult.

Unsuitable risks.

See Chaps. I. & II.

Disadvantageous to purchaser.

Speculation fostered.

Appraisement in advance impossible.

in many kinds of contracts to know at the beginning the quantity of work to be done or goods to be supplied, that some fluctuating or movable measure of value by which the price or purchase-money may be adjusted becomes necessary.

Purchase by schedule rates.

Simple instances.

Schedule adopted to save time.

Schedule tenders compared.

Difficulties.

Schedules to allow for variations.

Limit of variance.

Fixed sum as basis.

Additions and deductions.

(*b*) *Schedule Rates*, or the purchase of goods by units of price, instead of for a fixed sum of money, is often convenient and even necessary. Thus, to take a simple case, a cargo of coal may be bought at a rate per ton, the buyer and seller, who know approximately the tonnage, being alike indifferent when they make the bargain as to the exact quantity which the weighing after purchase will disclose. A contract for the construction of a railway tunnel may be made at agreed rates per cubic yard for excavation of different kinds of material, the proportion of each kind being unknown when the contract is made, leaving for measurement as the work proceeds, or, after completion, the quantities achieved. A schedule is sometimes preferred to a fixed sum merely to save time, as a manufacturer or contractor will more readily estimate the cost of certain work per unit than the total sum, which can only be arrived at by an exact calculation of quantity from drawings, which may not have been completed when the contract is made. Or, schedule rates may be sufficient to allow comparison between competing tenders, and the trouble of calculating and agreeing on the quantities may be taken only before the contract is entered into. But if there be many items in the schedule, it is often difficult without an approximate knowledge of the quantities to compare such tenders. Sometimes a schedule is preferred to an absolute sum, not to save the trouble of calculating the quantity in advance, but because it may be difficult to carry out the work exactly in accordance with calculated quantities. Thus, a large iron roof or bridge may be purchased at a rate per ton, the manufacturer obeying the drawings set before him, but being paid on the actual weight supplied; for as it is difficult in rolling or casting iron to arrive exactly at a calculated weight, a purchaser may prefer to pay only for what he actually receives; protecting himself perhaps by prescribing the limits of variance he will allow from the calculated quantities. Sometimes a fixed sum is adopted as a basis, and an addition or deduction allowed within certain limits to correspond with the actual quantity supplied. Thus, if the agreed price for an iron structure be £10,000, and the calculated weight 500 tons, £1 may be added or deducted for every hundredweight of excess or diminution in weight, and the right of rejection be reserved if the difference either way be more than 20 tons. But sometimes the condition is made to apply to one side only, a deduction being made for short weight but no addition allowed for excess. There are other cases in which an engineer intends to decide on the method and extent of works only as they proceed, and makes an imaginary schedule list of quantities to serve as the basis of a contract. But it is always desirable to approximate as nearly as possible the quantities in advance, as any great alteration from the anticipated quantities may cause loss to one side or the other. For instance, an engineer who wishes to have free scope for designing as the works proceed, may state as a rough guide to contractors certain quantities of excavation, masonry and ironwork, and ask for schedule rates to be appended to each. Probably the items of which there are the largest quantity will be valued at the cheapest rate. But if, as the works proceed, the quantities be reversed, then the contractor will lose in having to do small quantities at the low rate, and gain in the great quantities at the higher rates, and unless—which is unlikely—the alterations balance each other, there will be loss to one of the two parties to the agreement. And there is also the contingency that the works may be so increased as to be beyond the means of execution of a contractor quite capable of performing the anticipated work.

Imaginary list of quantities.

Risk of loss on one or other side.

Causes of loss.

A schedule may be summarised in one or few items, or may be indefinitely extended, each method having its conveniences. As an example of the first plan, certain goods which are to be purchased may, in regard to material, be composed of three kinds—iron, wood and brass, and one average schedule rate for each may suffice for measuring the price, even though there be a variety of each kind. Where the extent of the contract is sufficiently known from the commencement—for instance, where it is fully described by drawings or specification—such a limited schedule may serve, because, although the cost of the various kinds may differ, a contractor has an opportunity of calculating an average rate for each of the three items. But when the schedule is to be the measure of price for additions or omissions, whose direction and extent are unknown till they arise, the schedule would be likely to prove insufficient and inequitable, because all the articles comprised in the alteration might be of extremely high or low value, and the average rates therefore would not be fairly applicable. Although a minute division of the items may, as the schedule most likely to provide for every contingency, be considered the most

Short or summary schedules.

Minute division difficult.

effective, its very minuteness may be the occasion of difficulty. Thus, **And inconvenient.** if some extra commodity or work be required, to which no item in the list exactly applies, a new measure of value will have to be agreed upon, while a summary schedule which classed everything of one material together would include it. In the case of an undertaking of a varied nature, or which is likely to be protracted, it is sometimes sought to provide for items which may arise, not embraced by the **Unforeseen items, how paid for.** schedule, by stipulating that their cost price shall be disclosed and proved by the contractor, who shall be reimbursed his actual expenditure with a specified addition for establishment charges and profit. *See page 441.* This method somewhat resembles that of "Measure and Value," which will be presently referred to.

Grouping of items in schedule. Care and skill are needed in the division or grouping of the items in a schedule, so as to state each in the manner most suitable. There are accustomed units of measurement for different commodities, but **Various units of measurement.** knowledge of particular trades is necessary to their application. Not only are different articles or materials measured differently, but varieties of the same commodity also differ. Thus, ironwork is generally sold by weight, but for certain forms a lineal measure is employed, and occasionally—as in the case of buildings or roofs—superficial area. So timber is, in its earlier stages of preparation, sold by cubic contents, but when worked into certain forms, by lineal measure, and in others—such as flooring—by superficies. To the **Customary measures.** uninitiated, the classification sometimes may appear arbitrary or unnecessarily varied, but it is generally the outcome of long experience which has become expressed in trade custom. It is generally advantageous for the purchasers to adopt the measure usual in the trade, although cases sometimes arise where an analysis of the rates so stated may prove their unfairness, and some other measure of **Traders averse to new measures.** price may become expedient. Traders are generally averse to unaccustomed measures of quantity or price, and much foreign trade is lost by those who are unwilling to render their accounts in the manner **Subdivision for measurement.** preferred by the purchaser. Sometimes one kind of article has to be divided, and different methods of measurement applied. For instance, iron columns are generally sold by weight, but if on some or all of them elaborately ornamental capitals be required, these would be more fairly valued at so much each. Or, if timber or stone in a building be purchased by cubic measure, some fine carving **Proportion of labour to material.** would need another kind of appraisement. Indeed, where the cost of labour bears an unusual or extreme proportion to that of material, sale by weight or mere quantity of material is generally inappropriate.

Imperfect schedule misleading.

An imperfectly-drawn schedule not only renders an estimate of cost difficult, but often hinders the proper comparison of numerous tenders; and even although the total price demanded in each may be arrived at, an investigation as to which would prove most favourable in the event of extras or omissions may be difficult or impossible. If, for example, tenders be invited of prices for a schedule of one hundred items, of which no quantities are stated, it will be dangerous to assume that the tender which is lowest for the majority of items is really the cheapest; for even though cheaper in nine-tenths of them, yet if the quantity required of the numerous low-priced items be small, and the quantity of the few high-priced items large, the apparently cheapest tender may prove to be not so. Railway companies and others who purchase regularly stores of various kinds, often invite tenders, which are to be binding for one or more years, and a properly framed schedule should, for such a purpose, state approximate quantities, or, if no nearer guide be possible, the actual quantity of each article which has been purchased in past years. If one dealer has a knowledge, not shared by his competitors, of the relative quantities, he is evidently favoured. For if, secretly informed that of certain items large quantities are to be purchased, high prices are appended to them, while for the much more numerous items, low prices are appended, a high tender may be made to appear the most favourable one to those who adjudicate. Provision is sometimes made, in contracts for long periods, for adjustments to meet fluctuations in the value of materials. Thus, the regularly published prices of some leading commodity may be taken as the standard, and the contract prices, though not similar in rate or amount, may, in regard to fluctuations, be made to follow such published prices.

Schedule without quantities.

Fallacious comparisons.

Approximate quantities.

Corrupt dealings in tenders.

Tenders subject to adjustment for fluctuating values.

Money units not small enough.

Ordinary money units are not, in some cases, small enough, and percentages of increase or diminution have to be employed for adjustment. Thus, for example, the measure of quantity for certain commodities may be so small as to require units of pence as the price; and farthings as the smallest denomination may not allow with sufficient minuteness for subdivision or fluctuation. But the price having first been stated as nearly as may be in money, the aggregate sum for which a quantity of such commodities is sold can then be further altered by one-hundredth parts or fractions of one hundred. Indeed, in certain trades the whole adjustment is so arranged, and permanent

Adjusted by percentages.

Permanent price-lists so adjusted.
See TUBBS, *page* 657.

Disadvantages.

price-lists are adopted by all dealers, fluctuations in cost or the competitive prices of traders being entirely expressed by percentages. It is to this custom that the apparent anomaly is owing of prices being sometimes subjected to diminution of as much as 80 per cent. The adoption of the decimal system of coinage, which allows of infinite subdivision, would render this double and sometimes clumsy method unnecessary. Besides the trouble it involves, the plan has the disadvantage of facilitating overcharge by retailers, who, by exhibiting printed price-lists to uninitiated purchasers, may obtain more than a usual or legimate profit.

Percentages added.

Schedules with fixed rates.

Percentage added or deducted.

Reasons.

Adjustment by percentage is in the majority of cases downward, but sometimes it is upwards. Thus the price of sea-freight for merchandise is usually subject to an addition, known as "primage," of from 5 to 15 per cent.; and this, which probably in its origin was an independent charge for some separate service, is now merely a part of the price. A peculiar system of schedule, with fixed rates, is adopted by certain Government departments where contracts for repairs or other services, whose extent cannot be ascertained in advance, are continually occurring. The schedule embraces such items of labour, material, or other commodity, as have been found by experience to be required; and against each item is a printed price or rate, each competitor being required to state at what percentage above or below the printed rates he will execute the work or supply the commodities; and the most advantageous offer is so ascertained. The quantity of work done is measured, and the bill drawn up at the printed rates, and the percentage added or deducted at the time of payment. This method is adopted partly because it suits peculiar systems of account-keeping; but mainly, as already stated, because the ordinary money units are not, in the case of certain commodities, sufficiently minute.

Bill of quantities used as schedule.

Deposited with tender.

Where an elaborate or detailed bill of quantities is provided as the basis of a contract, and where the price has to be stated in one total amount, it is often considered that the bill, with a rate appended to each item, will form the best possible schedule for any additions or omissions which may be afterwards made in the contract. To carry out this plan, each competitor is called upon to deposit with his tender the detailed bill of quantities so priced out; although generally the deposit is under seal, which is only opened when the need arises, and in the case only of the competitor whose contract is accepted.

But there are certain engineering undertakings in which it is very

Difficulties in framing schedule.

Valuing additions and omissions.

Differential rates.

Instances.

See PILE-DRIVERS, *page* 847.

One schedule rate inapplicable.

Rates varied and subdivided.

difficult to frame a schedule which shall apply fairly to additions or omissions. The custom of including every charge in a rate according to quantity demands, in some cases, peculiar subdivision to make it safely applicable. Thus a contractor may have to provide expensive plant, machinery, and apparatus, the extent or cost of which would be but slightly altered if the quantity of work were to be diminished or increased. Therefore, having these fixed expenses already provided for, extra work could be performed at less rates than those in the primary contract, while deductions in price for omissions should also be made at a less rate, because the contractor would only save the material and labour deducted, and not a like proportion of his apparatus and fixed charges. To meet cases of this sort three schedule rates may have to be agreed upon for one item. An example of this kind would be afforded by the case of a harbour or jetty, in which timber piles may be scheduled at a price per cubic foot. In this item the contractor must include a proportion of the numerous fixed charges which have to be incurred, but of which only some pertain immediately to the piles. Thus, the cost of boats, staging, and appliances, as well as superintendence, risk of wreck, or delay from storms, have to be provided for; and accordingly a price per cubic foot is stated which may for timber seem very high. Now if, after the contractor has provided for staging and machinery, the engineer diminishes the number of piles or reduces them in size, a deduction at the primary schedule rate would deprive the contractor of more than he would save by the deduction; while, on the other hand, if the quantity of timber were much increased, the schedule rate would give him too much. And even if a separate schedule rate per lineal foot of driving the piles be provided, the same discrepancy would arise if alterations occurred in the length driven, as not only the staging and machinery have in any case to be provided, but the piles prepared, conveyed, and pitched in place, whatever be the depth of their insertion. Experience in particular kinds of works, and a mutual consideration between engineer and contractor, will alone allow an equitable adjustment in such cases.

Partial use of schedules.

As in the case of repairs.

Schedule rates are of great service in diminishing the uncertainty of charges, even when they cannot exactly regulate them. Thus, although it is often difficult to estimate beforehand the expense of repairs, at least many of the rates may be agreed upon in advance. For instance, if a steamer is to be repaired or refitted in a dock, the rent of the dock per day, the wages per day of the different artificers,

How limited.

and perhaps also the prices of material, may be arranged, thus affording the employer considerable check on the charges. But schedules of prices, unless made subject to addition or alteration, seldom prove sufficient for repairs; for the discovery of unforeseen defects, which may also have to be repaired as the works proceed, the consequent delay, and other circumstances, would often operate unfairly against one or other side.

Measure of price by units of contents.

Where applied.

Valuing ores by analysis.

See MINING, *page* 385.

Variable quality.

Price per unit.

(*c*) The measuring of price by *Units of Contents* is necessary in the commerce of certain commodities, liable to variation in their composition or richness, which can only be conveniently ascertained after purchase. It is chiefly raw materials or chemicals that demand this kind of appraisement; alkalis and mineral phosphates being among the most important of the latter. As an example of the former, the value of ore obviously depends upon its richness; and as the produce even of the same mine continually varies, or is combined with a varying amount of other ingredients, an analysis of each lot purchased can alone determine its value. Of course there are simple cases where long experience has proved that an average quality may be depended on; and where this happens with ores of low value, an occasional analysis may be considered sufficient, especially if the ore is to be used in the vicinity of the mines, so that the results will soon be known. But if the ore be variable, or contain ingredients differing in worth and liable to vary in their proportionate quantity, careful analysis can alone determine their value for any particular purpose; and as it would be inconvenient and expensive for a seller and buyer to examine and analyse with sufficient minuteness before bargaining, it is usual to buy while the exact quality is as yet unknown, and to agree on a price to be paid for each unit of one or more ingredients, the amount of which the analysis will disclose.

Sale of chemicals by simple units.

Ores sold on basis of price per ton.

In the sale of chemicals, payment is usually made for the aggregate of units at an agreed rate per unit. Thus a sale of mineral phosphate may be made at 12*d.* per unit per ton, and if analysis shows 65 per cent. the price will be 65*s.* per ton, and if 60 per cent. 60*s.* per ton. But in the case of ores it is usual to make the contract at a certain rate per ton, and then to add or deduct according as the analysis shows more or less than the standard of quality that may have been agreed upon. For instance, a contract may be made for iron ore at the price of 10*s.* per ton, on the assumption that it will yield 60 per cent. of metal, and it may be stipulated that for every unit above and

Adjusted by units.

See PYRITES, *page* 367.

Graduated unit price.

See IRON, *page* 385.

below 60, 3*d*. per ton shall be added to or deducted from the price. The two parties to the transaction are generally willing to make a bargain of this kind, because they are aware beforehand, within moderate limits, of what the quality will actually be, for the unit price may not be appropriate beyond moderate limits. For instance, if the metallic yield of the ore be less than 50 per cent., the purchaser may have the option of refusing it, for the expenses of fuel, manipulation and carriage may render such ore almost valueless. Or instead of having the right of absolute rejection, it may be stipulated that the rate per unit tó be deducted shall increase as the quality becomes poorer. On the other hand, a very rich ore may be worth more than is represented by the ordinary unit price, so it may be agreed upon that for every unit of contents above 65 per cent. 5*d*. shall be the rate of increase in the price per ton instead of 3*d*.

Simple units not always sufficient.

Compound units.

Manganese an instance.

See page 331.

A contract of this kind, based on what may be called simple units, does not, however, suffice for ores not depending for their value merely on their gross metallic yield, and adjustment of price by compound units becomes necessary. Thus, for steel-making, a particular ore may be purchased because of the manganese it is supposed to contain, in addition to the iron which is primarily necessary. As an example, such ore may be purchased at a nominal price of 12*s*. per ton, on the basis of 30 per cent. iron and 15 per cent. manganese, subject to an addition or deduction of 3*d*. per unit for more or less iron, and 9*d*. per unit for more or less manganese, the purchaser having the right of rejection if either of the ingredients or the total metallic yield fail to reach certain specified percentages. There may be also the stipulation just referred to, that the unit price may be increased when a certain richness is exceeded.

Correctness of analysis.

Sampling.

See page 426.

Analysis of sample.

In contracts for large quantities of ore, on such terms as those just described, the correctness of the analysis is of the highest importance, both to the seller and buyer, and the correctness of the sampling is of no less importance, and is a matter of real difficulty when the substance is not homogeneous. Representatives of both seller and buyer are generally present to assist at the sampling, which is effected either at the mine, at some place of transfer or shipment, or at the place of delivery. It is usual to agree upon a sample as correct before proceeding to the assay, as complicated disputes would otherwise arise. A sample is generally divided into three parts, one each for the seller and buyer, who each employ an analyst, and the third, in case of dispute, for the analyst who is appointed as umpire. Sometimes, however, the result of one impartial examination is agreed upon as the basis of an invoice.

Disputes.

Disputes sometimes arise in contracts of this sort from an alteration in the ore after the sample has been taken. When exposed to change in weather or climate, or to the vicissitudes of a sea voyage, ore—especially if it be in a loose powder state—will absorb moisture. A shipowner or carrier, whose freight is paid on gross weight, is not always disposed to protect his cargo from moisture. Disputes sometimes arise in regard to the added or deducted units, upon which the possible profit to seller or buyer may entirely depend. To be quite safe, a purchaser should assume as likely to occur the worst result from the analysis which the terms of the bargain allow, for, presumably, the unit tariff has been arranged so as to meet fairly any results which the analysis may disclose.

Alteration after sampling. *See page* 350.

Unit tariff should always serve.

Scientific methods.

The application of scientific methods to commercial valuation has enhanced greatly the necessity for qualified analytical chemists, whose services are likely to be in increased request both for this purpose and for the processes of manufacture.

CHEMISTS, *see page* 348.

Payment by results accomplished.

(*d*) *Payment by Results accomplished* may be agreed upon, either on the basis of a sum of money, or by schedule rates; but such an agreement generally differs from ordinary contracts for the supply of goods or the performance of works, in that the method is left entirely to the contractor, who, moreover, may not be entitled to any remuneration whatever if he fail in attaining the specified result. Thus, the pumping-out of a dock or lake, the recovery of sunken treasure, the raising of a sunken ship, the finding of minerals in a doubtful mine, the deepening of an estuary, the removal of a river bar, or the navigating some small or peculiar vessel across the sea, are speculative works which may be undertaken under this form of contract. This method of payment is sometimes adopted by public bodies and others, who have not the right or inclination to spend the funds entrusted to them on undertakings whose success is doubtful; and as it may be difficult or impossible to make a separate contract of insurance to cover the risk, they accept the offer of some speculative contractor who takes the risk of failure, but who demands in consequence, remuneration in the event of success which will leave a more than ordinary rate of profit. To the spirit and enterprise of such contractors, the carrying out of many important works which would not otherwise have been attempted is due.

Instances.

Reasons for using this method.

Speculative contracts.

Advantages.

(*c*) *Measure and Value* become necessary for arriving at a price where no contract has been made; and even in undertakings for which schedule rates have been agreed, goods, or works, or services, not contemplated or provided for in the schedule, demand this kind of appraisement.

Payment by measure and value.

A buyer may by his own knowledge, or by a trust in the fairness of the seller, be so satisfied in regard to the charges as to pay them without demur; or a price may be arrived at by haggling; or, failing agreement, the evidence of experts who measure and value the commodities may become necessary. The buyer sometimes seeks to check the charges of the contractor by keeping an account of the workmen's time and measuring the materials as they arrive. A seller is only entitled to a reasonable price, and in case of dispute must prove that his charges are fair. On the other hand, a buyer who has taken delivery of goods without previous agreement as to the price, cannot return them when he learns the price, but can only require that they be impartially valued. Arbitration is generally appealed to in disputes concerning value; and in England, even when a legal tribunal is preferred by the litigants, judges are disposed to encourage, and sometimes almost to enforce, the reference to an arbitrator rather than to a jury. The provisions made in engineering contracts for arbitration are often directed specially to disputes in price, and, if fairly arranged, afford a convenient mode of settlement. But it is essential that the appointment of the arbitrator and the conditions of hearing shall command the confidence of both sides.

Price, how arrived at.

Contractor's charges checked.

Only entitled to reasonable price.

Arbitration.

See page 420.

CHAPTER XVII.

CONTRACT AND PURCHASE (CONTINUED), PURCHASE FOR EXPORT.

Technical difficulties.

Purchases for public works.

Organisation for purchase.

Officials and agents.

Not available in small undertakings.

In the conduct of the engineering trades technical considerations are involved which are unusual in ordinary mercantile affairs; and difficulties arising from this cause are increased in the case of foreign transactions. Notwithstanding the establishment of iron-works and engineering factories in the principal colonial cities and elsewhere, the demand from Europe still continues and extends. Where the demand is connected with large public works, as, for instance, where railway material or equipment is required, it frequently happens, especially in connection with large and long-established undertakings, that for obtaining what is required a complete organisation exists. If Great Britain be the country of manufacture, there are engineers ready to design or specify; Government or other officials to buy, inspect and forward; bankers to provide funds; and, indeed, every means by which economy and fitness may be ensured. But in new and smaller undertakings, and for the multitude of private enterprises in foreign countries, such a complete organisation is obviously impossible, and it is to cases of this sort that the following remarks are mainly directed.

Subdivision of trades.

See FACTORIES. *Chap. XVIII.*

There is an increasing tendency in all trades towards subdivision, and factories are confined to the production of a few specialties where formerly miscellaneous work was undertaken. Special tools and processes are continually being introduced, and almost invariably the manufacturer who by these means does his work best, does it cheapest also. It is very difficult for a purchaser in a distant country, even if he be an engineer, to keep himself acquainted with the changes and improvements that are constantly occurring in the country of manufacture; and if not an engineer, it is almost impossible. To these difficulties must be added the fluctuations in prices, which are peculiarly inconvenient when intercommunication occupies much time.

Constant changes.

Fluctuations in price.

The cost of all manufactures is greatly dependent on the current prices of material, notably—in the engineering trades—of iron, steel, and coal, and these prices have at times been double those at another. While, however, the normal prices of manufactures are determined by the cost of production and the amount of profit which will tempt manufacturers or sellers to carry on the trades in question, the current prices and fluctuations depend, not upon the cost, but upon the demand; for if this be greater than the supply, sellers have the advantage until time enough elapses to allow new factories to be built or the supply to be increased. On the other hand, if the demand be slack, the competition of manufacturers who wish to keep their factories employed, or of dealers who must sell their stock, will bring down prices to, or even occasionally below, cost.

Normal prices, how determined.

Current prices depend on supply and demand.

The prices of plain or of heavy goods, in which the value of the material is large in proportion to the labour expended on it, obey immediately (when trade is in a normal condition), by rising or falling, every alteration in the price of material. But where only a small proportion of the total cost is for material, slight fluctuations in the value of the latter have little or no effect. Thus, the prices of railway chairs or heavy iron pipes will vary from day to day with the rates current for pig iron; the prices of bar iron will follow rather more slowly, because other outlay—such as that for puddling—comes between; while the selling price of a steam engine may remain the same though pig iron rise or fall ten shillings per ton. But if any great alteration occur in the cost of material, or if even a moderate alteration be long maintained, the prices of the finished commodity will alter also, not merely because the material has an enhanced value, but because a considerable or long-maintained rise usually signifies a general briskness of trade. Such fluctuations in the cost of material are of special consequence in international transactions, because much time may elapse before a bargain can be concluded. A manufacturer of railway chairs could not, without risk of loss, keep an offer open for acceptance for longer time than a week, unless the

Prices follow cost of material.

Some prices follow slowly.

Fluctuations inconvenient in foreign dealings.

Offers kept open.

tendency of prices was obviously downwards, or unless he added to the price something by way of insurance, thus, in effect, making the offer a speculative one. A manufacturer of bars or plates, to whom the price of pig iron is not of such immediate consequence, could venture further than the maker of chairs, and would probably, in a similar condition of the market, hold the offer open for a fortnight; a maker of bridges perhaps for a month; while a locomotive builder would seldom hesitate to leave an offer of price open for acceptance for three months, though, in all these cases, there would be a risk that during the interval the factory might become fully occupied with other work. If it is desired to avoid these disadvantages of distance by the use of the telegraph, care must be taken to avoid ambiguity. Where the transaction is one frequently occurring between regular correspondents, the conditions and details may generally be arranged in advance by letter, leaving only the bare statement of price to follow by telegraph. It is unnecessary to describe here the elaborate and ingenious codes by which telegraphic communications are facilitated and cheapened; and there are codes specially prepared for the engineering trades. But where no preparation has been made in advance, then the telegraph should, if possible, be only used in one direction, full details being given by letter in the other. The circumstances of each case must determine whether the inquiry or the reply should be by telegraph.

Transactions by telegraph.

How arranged.

Engineering material, choice for export.

In choosing engineering material or apparatus of any kind, and for any situation, there are always circumstances to be considered other than the direct or immediate purpose for which they are required; and when the articles chosen are for export to a foreign country, these secondary or subsidiary incidents become more numerous. The weight which any or all of them may have depends, of course, on the circumstances of each particular case. It may, however, be convenient to summarise them here as follows:

1. The Cost and Risk of Sea Carriage. *See page* 445.
2. The Import Duties which may be imposed. *See page* 448.
3. The Difficulties and Cost of Transport Inland. *See page* 449.
4. The Difficulties and Expense of Erection, Setting to Work, or Treatment at the Destination. *See page* 450.
5. The Exigencies of Locality, Climate, or Space. *See page* 452.
6. Methods of Payment. *See page* 452.
7. The Rate of Exchange of Money. *See page* 455.

(1) *The Cost and Risk of Sea Carriage.*—The prosperity of a manufacturing country depends as much upon the facilities for shipment as upon the facilities for manufacture. The price at the place of destination is that which really interests the purchaser, and the cost merely at the place of manufacture will, if taken alone, mislead, as it is only one of many incidents which must be considered together. The price of freight is determined by a variety of circumstances, some of which, at first sight, appear to have little relation to the matter. The primary conditions are the size, shape, and weight of the pieces to be carried, and the length of the voyage; and where the export of the goods in question forms a regular staple trade of importance, the cost of freight is mainly determined by these conditions, although the actual price of freight—like that of any other commodity—is liable to extreme variations if the demand suddenly grow or diminish. But it is seldom that material connected with the engineering trades is alone sufficient for complete cargoes, and the shipment of such material either only forms in each case part of a cargo, or, as in the case of large quantities of rails or other railway equipment, is effected by chartering a vessel specially for the voyage. Engineering material is generally heavy in proportion to its bulk; and where this is the case, shipowners, while they would be averse to taking a shipload of it, are glad to have it with other cargo, because of its utility as ballast. Variety in the *kind* of merchandise conveyed tends much to cheapen the cost of sea carriage, for both light and heavy goods are needed for the advantageous stowage of a ship. It is because woven fabrics and other light merchandise are exported so abundantly from Great Britain, that the products of the engineering trades are conveyed so cheaply. The freight for heavy goods is charged by the ton of 2240 lbs., and for light or bulky goods by the measurement ton of 40 cubic feet, the shipowner having the option of choosing the method which gives him the highest freight. Sometimes, however, special contracts are made by which weight only is reckoned, this course, for instance, being expedient sometimes in the case of bridgework or pipes, where some of the pieces, if strictly measured, might be charged at rates unduly high. For very heavy or bulky pieces, such as locomotives, boilers, or thrashing machines, ordinary rates do not apply, and a special bargain is made. The current rate of freight depends also on the likelihood of a profitable return voyage. As in an inland trade reciprocity cheapens transport, so in a foreign trade, low rates of freight outward are

Sea carriage.

Rates of freight, how determined.

Miscellaneous cargo.

Chartering.

Heavy goods useful as ballast.

Weight and measurement tonnage.

Special contracts for freight.

Return Cargoes.

Free-trade reduces freight.

Return cargoes determine rates outward.

Instances.

only possible where imports are encouraged; an unrestricted intercourse between nations, and the consequent employment of ships, being among the benefits which a wise policy of free-trade affords. Thus, if there is a heavy crop of tea in China, or of cotton in India, so many vessels may in each case start to fetch it, as to make outward freights cheap. The profitable return voyage, to have this effect, need not even be to the same country. For instance, the selling price at Philadelphia of Spanish iron ore (of which large quantities have been sent to the United States) will be affected by the fluctuations in the price of wheat in London, because high prices in England encourage the export of corn or flour from America, and the prospect of such corn cargoes, inducing an increased number of European vessels to cross the Atlantic to fetch them, has the effect of reducing freights westward. On the other hand, freights sometimes suddenly rise because of a demand in another direction. Thus, to take a similar example, if much corn awaits shipment in Odessa, vessels will be attracted thither instead of westward, and freights to America will rise.

Proximity to port of shipment.

Land carriage dear.

See MINERAIS, *page* 353.

Choice of port.

English ports for coal and iron.

See COAL, *pages* 363 & 530.

Chartered vessels.

Customary ports.

In making contracts for machinery or engineering material, the proximity of the factory to the port of shipment must be considered. The cost of carriage to the port often amounts to as much as, or more than, the freight by sea to a distant country; and this circumstance, of course, is of increased importance for those commodities in which the expense of carriage bears a considerable proportion to their total cost. Where the goods are in large quantities, as is often the case with coals or railway material, a vessel may be sent to the nearest port to fetch the cargo, instead of the cargo being sent to a port which suits the vessel. For instance, in Great Britain, steam coals and railway iron are shipped from Newport and Cardiff; coals, pig iron, and pipes from the Tyne, the Tees and the Clyde; while the largest proportion of machinery and general engineering material is shipped at London, Liverpool, Glasgow and Hull. At whatever port cargoes are lying, vessels may, as just mentioned, be chartered to go there and take them. But even where the goods offered are not sufficient to fill a vessel, they may be enough to induce a shipowner to send his vessel to call at a particular port to fetch them, to complete a cargo commenced or finished elsewhere. But although vessels to any foreign country may sail indifferently from any British port, it has become the custom, either because of the exigencies of the homeward trade, or because certain harbours are suitable for the vessels in question, or for other economical reasons, that particular trades or destinations are associated with particular ports of departure, and the larger proportion of machinery shipped from Great Britain has to go with other and miscellaneous cargo from these customary ports.

Order of shipment.

Packing and stowage.

The strength of the goods to endure the risks of transit; the order or sequence in which shipments shall be made; the best methods of packing; care in loading; the security of stowage on deck or in the hold, are all matters which demand attention, especially in the case of heavy, bulky, or fragile cargo, such as boilers, locomotives, roof-work or light castings.

Bills-of-lading.

Liability of shipowners.

Special provisos.

As to damage.

Liability should be allotted.

C. i. f. Contracts.

When cargo is shipped, bills-of-lading are signed, by which the owner or agent of the vessel undertakes to deliver the goods at their port of destination in good order and condition, unless certain accidents or events which are specified in the bill-of-lading, relieve him from his liability. Shipowners frequently seek to reduce their responsibility as carriers by introducing into the bill-of-lading special clauses, favourable to themselves; and while it is doubtful how far such exceptional stipulations can be legally enforced, it is advisable for the shipper to protect himself either by insisting on proper terms, or by insurance against the loss of or damage to his goods that may occur upon the voyage. The total cost at a foreign port of arrival of a cargo of cast-iron pipes will not, however, be comprised in the original purchase money, with the expenses of freight and insurance added, unless the liability for breakage be also allotted. A bill-of-lading excludes this liability and underwriters will seldom insure it. Therefore a contract to supply goods C. I. F. (cost, insurance, freight) leaves to a buyer risks which he avoids when the seller has contracted to deliver the goods at the port of arrival. In the latter case, the seller takes all the risks—insuring as best he can—and must replace anything lost or damaged.

Marine insurance.

Premiums.

Particular average.

The percentage of premium paid for marine insurance is determined by various conditions, such as the direction and probable duration of the voyage, the age and character of the vessel, the nature of the cargo, and in some cases by the season of the year in which the voyage takes place. Insurance can be effected to include, besides the risk of total loss, that of partial damage (if amounting to not less than 3 per cent.), when it arises from perils of the sea; and on ordinary merchandise it is generally advantageous to insure in this way, technically called "insuring with average." It is usual, however, to exclude this part of the risk when insuring iron or rough cargoes, policies being then effected "free of particular average" (f. p. a.), the underwriters being then freed from liability for partial damage, unless "the vessel be stranded, sunk or burnt," in either of which cases the underwriter has to pay for the damage or expense, whether it arise in consequence of this special casualty or not. It need hardly be said that, other circumstances being equal, the premium is larger in the case first mentioned than in the second, and the underwriters naturally stipulate that the goods shall be suitably packed or protected. In voyages to the East Indies, China, or the Australian colonies, premiums hardly vary at all on account of the season of the year, but on shipments to the Baltic or Black Sea, to North American ports or to the West Indies, the rates of premium are very much higher on vessels sailing in the winter.

Particular average (f. p. a.).

Fluctuations in premium rates.

Advantageous to buy high-quality goods only.

Where the expenses of freight, insurance and import duties are considerable in proportion to the cost of the goods at the place of manufacture, it is obviously unprofitable to obtain a small saving in the original price by accepting goods of an inferior quality. Thus, if 10 per cent. be saved in the cost of the goods with a presumable equal reduction in quality, it may be found, when the freight and charges have been paid, that the saving when calculated on the total outlay is only 2 per cent., while the inferiority of quality still remains 10 per cent.

See IRON, *page* 542.

Import duties.

(2) *Import Duties* are imposed on engineering material in almost all countries except Great Britain, either for the purpose of revenue or for protecting home manufactures, or for both these purposes. Without discussing here the wisdom or fallacy of such duties, they have often to be considered in the export of engineering material. Sometimes the dues are levied *ad valorem*; in other cases they are calculated at a fixed rate by measure of weight or quantity, according to the nature of the material; and the merchant or importer has to be guided, not by what is best suited to the purpose in view, but by the necessity of entering under a low tariff. Thus, it is possible sometimes, to obtain an advantage by substituting one kind of material for another, as, for instance, cast for wrought iron, or iron for steel. Where customs dues are imposed without discrimination according to the kind of material of which the goods are made, and not graduated *ad valorem* according to the different qualities, it is to the interest of the purchaser to import material of a high quality. As

Protective duties.

Duties, how levied.

Choice of goods affected by duties.

Instances.

Low tariffs for raw material.

Loss caused to importers.

Makers guided by tariffs.

an example, if the price of good tool-steel be 8*d.* per lb., and an inferior quality be only 4*d.* per lb., and if the duty on both be 4*d.* per lb., it is obviously economical to purchase the best. In other cases the goods imported may, by the omission of certain workmanship, be brought within the lower tariffs which prevail for raw material. For instance, in a steel bridge, the bars or plates may be sent without any holes punched or drilled in them, and so in some countries be admitted at a much lower tariff than would be imposed on the finished article. It is true that the addition of such holes, and the after-fitting together of the structure, may only be effected in the importing country at a cost four times as great as the cost would have been in the manufacturing country, and the work be done in a less effective manner; but though this extra cost may be £2 per ton, against this perhaps £5 per ton may be saved in duty. This loss, however, falls actually on the importing country, and need not be considered by the exporter. Or to countries where steel rails are admitted only under a high duty, blooms (i.e. ingots reduced by rolling ready for the rail-mill) may be sold at a price almost equal to that of the finished rail because the importer can bring them in at a lower rate of duty. Sometimes it is even cheaper to completely finish the goods and then to undo some of what has been done so as to bring them under a low scale of duty. Thus weldless railway tires made cheaply by machinery have at times been cut before shipment, because as "bent tire bars" (which will require welding and so provide employment in the importing country) they were admitted cheaply. Where there are imposts of this sort, the engineer or manufacturer should be furnished with the tariffs, and with a full explanation concerning those rates which bear on the case in question, so that they may help to determine the choice of commodity to be exported. Even when there are treaties limiting the duties that may be imposed, the obligation is sometimes evaded in the importing country by the issue of new regulations or conditions of contract that all goods wanted for enterprises over which the Government or Legislature have control shall be made at home, irrespective of price.

Transport inland.

See also pages 176 & 451.

Choice of evils.

(3) *The Difficulties and Cost of Transport Inland.*—There is sometimes great difficulty in transporting heavy ironwork or machinery from the port of arrival to its destination, and difficulties of this sort should be taken into consideration when the machinery is designed. The question often resolves itself into a choice of evils. It must be

Large pieces with costly carriage.

Or light pieces numerous.

See STEAM-ENGINES, *pages* 592 & 597.

estimated whether it will be cheaper to carry at great cost, the large or heavy pieces which are best for the ultimate purpose, or to make the pieces lighter by the use of high quality material (such as steel), or by subdivision, to make them lighter because more numerous. This latter course may render necessary the export of machines which have not been completely finished and proved, and the expense of bolting together or riveting at the site, which would be avoided by sending larger pieces.

Difficulties at site.

Choice guided by facilities in importing country.

Designs modified for foreign use.

Improved machines may be too complicated.

Difficulties often over-estimated.

(4) *The Difficulties and Expenses of Erection, setting to work, or treatment at the Site.* In choosing machinery or engineering material, the final cost when complete on the site, and fitness for the purpose in view, are the two principal questions which have to be considered, and there need be no hesitation in selecting for use in the country of manufacture what best satisfies these conditions. But in foreign countries the intending purchaser has to consider how far he will be able to utilise his material when he has imported it, and whether he has qualified engineers or workmen to erect, set to work, or otherwise complete it. The articles in question may be so simple as to need no special skill, or may be already in such common use as to have afforded experience, and to have created a class of workmen who sufficiently understand them. The engineer or manufacturer, if properly informed by the purchaser of the circumstances of the case, can often, by slight modifications, facilitate the work which will have to be done abroad, or can advise the substitution of some things simpler than would be used in the country of manufacture. In machinery and apparatus of all kinds, improvements are continually being devised which allow economy in maintenance, or in cost of working; and while many such improvements are in the direction of simplicity, others, not unfrequently, are of a delicate or complicated nature, demanding skilled supervision. It is then, of course, a question for the purchaser and for the engineer who advises him, how far it will be prudent to establish such novelties in a foreign country; and whether a ruder or simpler kind will not be better adapted to the circumstances of the case. On the other hand, purchasers, especially when they are not engineers, are apt to over-estimate the difficulties of dealing with machinery or engineering material in a foreign country. This tendency leads them to attach too high a value to those articles which, being complete or self-contained when they arrive, need little or no skill for erection or

setting to work. It is owing to this, that portable engines are used in many cases where a fixed engine would be better and more durable; that bridges which can easily be bolted together are chosen in preference to those that may with more advantage and safety be riveted; or that wrought-iron tanks (occupying much space for freight) which are ready for use when they arrive are preferred to the stronger and more permanent tank composed of cast-iron plates that are more easily carried, but which have to be bolted together and caulked at the site.

Instances.

See BRIDGES, *pages* 142 & 176.

See TANKS *page* 639.

The question of maintenance or economy in working has also to be considered. Thus, a structure or the framework of a machine may be better made of steel than wood, but because skilled workers in steel, who can do repairs, are difficult to obtain, the question arises whether wood may not, under the circumstances, be preferable to steel. Again, there may be used in British workshops a special and expensive machine, adapted for one particular kind of service, which it performs quickly and cheaply. But in a foreign factory the amount of this particular work may be insufficient to afford constant employment to the special machine, and it may be more economical to import a tool which can be used for various purposes, even though, for the particular duty in question, it may be less effective. Or a steam-engine may be required in a country where fuel is very expensive, and where, by the use of a certain kind of engine and boiler, economy of fuel may be obtained. It may be expedient to purchase these, even if they cost more and are less durable than those of a simpler kind. It is obvious that very careful consideration of the different circumstances is needed in such cases. To meet exigencies of this kind in a foreign country, duplicate machines or duplicate parts may be purchased; and it may be expedient to incur expense which may be regarded as a premium of insurance against loss, a premium which would be altogether extravagant and uncalled for in Great Britain. The number of such duplicates, their cost, and the interest on capital which the keeping them in reserve involves, must be weighed against the length of time and consequent delay which would be required to import a fresh supply. Time may be saved by the provision in advance of a telegraph code referring to such parts.

Economy in working.

Special machines often too expensive.

See MACHINE TOOLS, *pages* 408, 687 & 740.

See BOILERS, *page* 575.

Effective machines costly to repair.

Duplicate parts required.

See page 592.

Involving capital outlay.

The stoppage of machinery, or the failure of material in the importing country, is a more serious matter than it would be in the manufacturing country, where repairs or renewals can be easily effected; and this often applies to the smallest detail. For this reason it is bad policy to import inferior articles, even though they be as good as would be used for the purpose at places within easy reach of repairs or replacement. Thus, in the case of wood-working machinery or the engine of a sugar-mill, the consequences of an accident might, if it occurred in the manufacturing country, be so easily repaired as to render undesirable any previous expenditure of capital to provide duplicate parts. But in the importing country such extra expenditure might be more than justified, as a safeguard against what would in effect be a serious disaster. This, added to the reasons already adduced against the false economy of exporting second-rate goods for engineering purposes, shows that the example of what obtains in a manufacturing country is not necessarily to be followed abroad.

Where repairs are difficult, inferior articles should be avoided.

Exigencies of climate, locality, and space.

(5) *The Exigencies of Climate, Locality, or Space.*—In the establishment of a factory, the erection of machinery, and indeed in almost every kind of engineering work, there are certain local circumstances which must be studied and satisfied if economy and fitness are to be obtained. If buildings are required, not only their purpose and a plan of the site, but also the levels, the nature of the soil for foundations, and the climate with its effects on material, as well as the exigencies of heating, cooling, ventilating, and lighting, are all incidents that affect the choice of design or the mode of arrangement; and where engineering material or structures have to be designed or manufactured in one country, in order to be erected or completed in another, it is obvious that full information should be transmitted to all concerned in the design or preliminary stages of the work. With such information as a guide, the necessity or expediency of altering the usual methods may be apparent, while, if such information be withheld, and only a bare enumeration of wants be supplied, the risks of unfitness or extravagance are greatly increased.

Building materials.
See FACTORIES, *page* 471.

See ROOFS, *page* 860.
See BRIDGES, *page* 174.

Methods of payment.

Contractor-capitalists.
See Chaps. II., III.

(6) *Payments* for works, goods, or services, become due when the obligations are fulfilled, unless there be some stipulation to the contrary. Deferred payments, and the speculative combinations of contractor and capitalist which often arise out of engineering projects and public works, have been already considered, and it is not necessary to allude here to the ordinary methods of payment usual

among merchants. But in the carrying out of works abroad, or the manufacture of engineering material for export to a foreign country, special circumstances have often to be considered. In some countries, payment of a portion of the purchase money in advance is usual, and, as "hand-money," is, by custom or law, essential to the closing of a bargain. In countries like Great Britain, where rules of credit properly guarded and limited are established, payments in advance are seldom required, except from foreigners or others who are not domiciled. Although, where the purchaser has confidence in the seller, this plan is simple, the alternative can be adopted of depositing the money with some banker or agent, who need only pay in the ordinary way as the contract becomes completed.

Hand-money.

Part payments.

The nature and extent of an undertaking often renders part payments necessary as the work proceeds, and should be provided for in the conditions of contract. For instance in the carrying out of a contract for a railway or other large undertaking, payments during construction have to be made; or in the manufacture of a large bridge of many spans, as each is delivered to the ship, site, or other place agreed upon, a proportionate sum on account has generally to be paid. If the works contracted for allow of very exact subdivision, each portion being complete and independent of the other, the payments during the progress may be the full equivalent of what has been performed. Thus, if 12 steam engines, or 12 bridges, or 12 miles of railway are contracted for, a purchaser may be willing to pay a twelfth part as each is complete and in his possession. But in the case of a bridge of numerous spans, or of some railways, or of a dock, the different parts may be so dependent on each other, that payments on account to the full extent of the part apparently completed may be inexpedient. It is usual, therefore, after calculating the money value of the completed work and the proportion it bears to the whole contract, to withhold some of it—a specified percentage, e.g. five or ten per cent., as may be agreed—till the contract is absolutely completed. The percentage to be retained is determined by various considerations, such as the nature of the work and the lessened or suspended value of the earlier parts if the remainder were not completed or were much delayed, being the principal.

As portions are completed.

Instances.

Retention-money.
See pages 4 *&* 37.

Caution-money.
See page 38.

Payments thus withheld are, in effect, caution-money (which will be forfeited if the contract be unfulfilled), the accumulation of which is, in large contracts, limited to a prescribed total; and when the percentages withheld reach this maximum, the after payments are made in full.

Part payment on shipment.

Arranged by schedules.

See page 4,2.

Contractors importing material.

Payers require possession.

Where a contract is made in one country for the carrying out of works in another, whither material and equipment have to be exported, it is often stipulated, where the undertaking is a large one, or likely to be protracted, that a portion of the purchase-money shall be paid on each shipment, although, till they have arrived and been applied at the site to the purpose in view, the material so paid for may be of no value to the purchaser. The arrangement beforehand of the proportions payable is a mattter of great importance to the contractor ; and, to avoid disputes, elaborate schedules are often appended to an agreement, declaring what proportions shall be payable at the various stages of shipment, delivery, completion and at the end of a term of maintenance. And the same arrangement is often made in the case of works undertaken by local contractors in colonies or countries where the material has to be imported ; and while the obligation and responsibility of obtaining the material remains with the contractor, the employer provides money in the manufacturing country to make the necessary part payments, taking care, by suitable agents, to ensure that the material so paid for is of the agreed kind and quality. Where part payments are made on shipment, the payer usually requires possession of the goods ; and though they may have to, be temporarily re-entrusted to the contractor at the port of arrival and until completion, the legal possession remains with the purchaser.

Part delivery may be impossible.

Instances.

Payment during construction.

As for steamships.

There are certain kinds of contracts where part delivery to the purchaser is almost impossible, and payments during progress cannot be met by giving possession of an equivalent part. A steamship or a large pumping-engine, where the total outlay of the builder may be greater than he can afford without part payment, are examples. There are certain stages in the progress of such works which indicate broadly the proportion accomplished, and it is usual to pay a portion of the purchase-money at such periods. For instance, in the case of a steamship, it might be agreed to pay one-fourth when the hull-frames are set up, the cylinders cast, and the boiler-plates drilled ; one-fourth when the ship is plated, the cylinders bored, and the boilers finished ; one-fourth when the vessel is launched and the engines completed and ready for placing on board ; and the final fourth part of the payment when the steamship has had a successful trial trip. In contracts of this sort, purchasers are naturally anxious

Purchasers require lien or security.

to have a lien on the property for which they have partly paid, but of which they cannot yet get possession; for in case the factory changed hands, or a mortgagee took possession, or the shipbuilder became bankrupt, disputes might arise regarding the ownership of the property. If the purchaser happens to be the owner of the building or soil on which the ship is being built, his right to the works in progress would be clear; and as such ownership of the premises is sometimes considered the simplest or only effective security, a legal conveyance is effected and retained till the ship is delivered to the purchaser. The same result is sometimes sought by the mere deposit of title-deeds or lease, with a declaration as to the property. But all such methods are inconvenient, and the seller may be unwilling, or even unable, to agree to them. It is often, therefore, considered sufficient to affix some notice or placard to the structure in question, so as to declare plainly the ownership. And the minor parts may be similarly identified by casting, branding, or marking each with the name or sign of the purchaser. Such marking, if accompanied by *bonâ-fide* evidence of purchase, and part payment, is considered sufficient to protect the property, at any rate to the extent of such payments, against the adverse claims above referred to.

Ownership of site or factory affords security.

Deposit of deeds

Name of owner affixed.

The rate of foreign exchange.

(7) The *Rate of foreign exchange* does much to determine money values and prices in the export of engineering material, as of all other commodities; but to the engineering trades the question is important in other ways than those in which it affects the ordinary merchant. Engineers, contractors, and the traders allied with them are, perhaps, more than any other classes, interested in foreign undertakings; and the payments for Public works, the guaranteed interest on investments, the tariffs for Railway, Tramway, Water, or Gas service, and salaries to engineers, are frequently made in the currency of the country concerned. Moveover, as engagements for matters of these kinds are often made for much longer periods than contracts for the purchase of merchandise, the risk and the effect of extreme fluctuations are proportionately extended.

Often important to engineers and contractors.

Rate of exchange, how determined.

Only a brief reference to so wide and important a subject as foreign exchanges is, however, necessary or possible here. The rate of exchange between any two countries is primarily determined by their relative indebtedness, so that persons who want to remit money to a foreign country, and who have to buy in the shape of a bill-of-

Countries with similar standard.

See GOLD, *page* 370.

Fluctuations, how limited.

Countries with different standard.

exchange money belonging to, or a debt owing by, some one in that country, will have to pay a price which varies according as the demand for such bills is greater or less than the supply. But in the case of countries having a similar system of currency—as, for instance, Great Britain and most of her colonies, or Great Britain and Germany, which alike have a gold standard—and where a par bullion value is established, a premium in either direction has only a moderate range, for it is limited by the cost of the alternative plan open to remitters of despatching bullion; the freight, insurance, and interest during transit of the bullion being taken into account. But when there is a different monetary basis, much greater fluctuations become possible, as is seen in the dealings between a country having a gold with one having a silver standard.

As gold and silver.

Fall in value of silver.

See SILVER, *page* 395.

Irredeemable paper currency.

Fluctuations unlimited.

Instances.

Mixed currency.

Temporary gain by fall in value.

Instances.

To the ordinary fluctuations just alluded to, arising from an excess of the flow of remittances in one or other direction, is added the alteration, whose range cannot be defined, of the relative values. An example of this is seen in the commerce between England and India, where a silver currency standard is firmly established. Although the relative value of the two metals has constantly varied, the tendency has, in the course of years, been towards a lowering of the value of silver; and the rapid fall since 1871 has caused not only inconvenience but loss to many concerned; for where goods have to be exchanged for something which fluctuates in value, and which therefore can hardly be called money, the commerce takes the form of barter rather than sale, and upsets all antecedent calculations. There is a liability to still greater fluctuations in the rate of exchange where an irredeemable paper currency is established; for although a strictly limited issue may maintain a certain level because of its purchasing power in the country itself, there is no limit to the depreciation which may result from an extended issue. The *assignats* of the French Revolution, and the greenback issue in the United States during the civil war, are cases in point. The question is still further complicated between countries which, like Austria, have both silver and paper currency, and countries like England, with a fixed gold standard. A reduction in the international value of a silver or paper currency, as seen in the rates of exchange, is sometimes a great advantage to many concerned, especially in large countries where such a currency has a wide circulation. For instance, in India or in Russia, if the value of the silver rupee or paper rouble fall, the peasants and others whose rent and taxes are fixed in the local currency pay for a time a sum no greater than before, while if they have produce to sell for export, they find that the price (which is determined by outside or international causes) gives them more than the usual number of rupees or roubles. But even this gain is generally only temporary or apparent, for international commerce is too extended not to bring values to their proper level in time, and the prices of commodities consumed rise. On the other hand, those whose incomes are fixed in the inferior money, but who, as in India, have to purchase imported commodities, or who wish to remit to a country having a currency based upon gold, suffer to the utmost from the depreciation.

Losses caused by falling exchange.

Tariffs paid in local currency.

If, in a foreign Gas-works, the agreed price or tariff for gas is paid in the local money, while coal has to be imported at its current value, and paid for in gold or its equivalent, it is evident that a great loss results from a depreciation of the currency. Or a Railway, or Tramway, or Bridge, made with British capital and on which interest or dividends have to be paid in sterling, may have tariffs and tolls fixed by law, which cannot be raised as the value of the local currency falls. The drainage works in Rio de Janeiro, some of the tramways in Argentina, and the waterworks in Odessa are examples of undertakings whose net revenues have fallen in gold value to the loss of the investors. Engineers, contractors, and others concerned in public works, are often of necessity obliged to accept payment in local currency; and even where British sterling has been the original measure of value, some fixed rate of exchange is often adopted as the basis of computation. It is, however, always expedient to provide for possible fluctuations by stipulating, either in general terms that the local payment shall be the equivalent of a specified sum in sterling, or with greater precision, that the payment shall follow the rates of exchange or be subjected to revision if the difference pass a certain moderate limit. There are various indirect causes which influence the rates of exchange between two countries, such as the scantiness of trade, which may limit the opportunities for remitting; the commerce of other countries with which each of the two may have relations; the uncertain credit of individuals or banks; but on these it is unnecessary here to touch.

Borrowed money bearing interest in sterling.

Fluctuations should be provided for.

Indirect causes of change.

British sterling.

British sterling is the best basis for international transactions. London has become, not only because of her vast commerce, but for various other reasons, the clearing-house of the world; and even to the foreigner, such a basis of computation is, because of its certainty, often convenient and desirable. But the ordinary quotations for rates of exchange are seldom for bills payable at sight, the customary usance, which varies with different countries, being generally for bills of from one to three months after sight by the acceptor; and this must be borne in mind when a bill on a foreign country is purchased for ready money. It is necessary, therefore, in stipulating for payments in a foreign country, "at the current rate of exchange," to remember that the ultimate payment will only be made after an interval, during which interest must be reckoned. But a special rate for a sight-bill will generally be quoted by a banker if required, and the current rate of exchange for a banker's bill at sight on London, payable in sterling, may be safely adopted in any country as the measure of value for international transactions.

Usance differs.

Banker's sight-bill a safe measure of value.

It will be seen from the foregoing pages that the secondary or subsidiary incidents enumerated on page 444 deserve much weight in the choice of engineering material, and that what may be the best of its kind for use in a manufacturing country is not necessarily so abroad. It too often happens that a purchaser who has seen or read of some new machine or material which has proved successful, desires to have the same thing sent to him abroad, without appreciating at their proper value the difference in circumstance which these incidents may cause. Engineers also, or manufacturers, who may be fully competent in the exercise of their profession, do not always give full weight to the contingencies of locality and circumstance which have been described. But although these contingencies, if known, may be provided for, unfortunately in a great number of cases they are not known to those immediately concerned, namely, those who have to design, manufacture, or supply the commodities required. The importance of sending full information from abroad, and the infrequency with which this importance is appreciated, have already been referred to.

Insufficient weight given to them.

See page 415.

To those in foreign countries who are surrounded by the same continually recurring circumstances or conditions, and to whom the facts of locality or purpose are perfectly familiar, it doubtless requires a special effort of mind to realise on what apparently simple and rudimentary points it is necessary to inform the engineer or manufacturer at a distance, to whom is intrusted the fulfilment of their wishes. It must be remembered that in a manufacturing country where demands centre from all parts of the world, ever-varying con-

Importance of giving particulars not appreciated.

Choice and design hindered.

Delay and expense caused.

Instances.

See BRIDGES, *page* 174.

See STEAM-ENGINES *page* 592.

See page 576.

Transport.

See PIPES, *page* 651.

ditions have to be satisfied, and to meet these differences there is a corresponding variety of methods. The choice among these methods depends upon local facts, for his knowledge of which the engineer is generally dependent on what is supplied to him by those on the spot. Sometimes important dimensions are omitted: in other cases the purpose which is to be satisfied, or the service to be performed, is not sufficiently described; or the method of payment, or the conditions of site or climate are omitted altogether. Delay is thus caused while the missing facts are being ascertained; and if, to avoid delay, a somewhat haphazard decision is come to, then, in the desire to be safe as regards strength or fitness, an unnecessarily great expense is generally incurred. As for example, a bridge of several spans is required, and the bed of the river is either not described at all, or merely alluded to as mud or sand. Nothing is said further as to the density of the bed or its suitability for foundations; and the engineer, assuming that the mud is soft, designs his piers accordingly. The foundations may prove to be firm, and it is discovered when the bridge is fixed, that much less expensive piers would have been sufficient. Ten pounds have perhaps been saved by omitting to examine the river bed, and five hundred pounds wasted in unnecessary screw-piles. Again, a powerful engine is required, and although the horse-power is specified, no particulars are sent as to the space into which it must fit, the service for which it is required, or the provision which is to be made for connecting it to existing machinery. As regards the boiler, no information may have been given as to the maximum size and weight of the pieces which can be transported to the site, or as to the fuel it is to consume. Or, to take another case, iron pipes are required, and no information is afforded as to the purpose for which they are intended, the pressure to which they will be subject, and the sort of place in which they are to be fixed. Perhaps there is no grievance upon which British engineers and the manufacturers allied to them would so unanimously agree as in regard to this insufficiency of information furnished from abroad.

CHAPTER XVIII.

THE ESTABLISHMENT OF FACTORIES.

Conditions classified.

THE conditions which favour the establishment of manufactories might, if they admitted of a rigid classification, be divided into those which are primarily necessary to the purpose in view, and into those secondary conditions which, though they may determine the cost of production and the amount of profit, are not absolutely essential. Among the first *Materials of Manufacture*, *Labour*, *Fuel*, *Water*, might take a place; and among the second—*Climate*, *Locality*, *Site*, *Transport*, *Contiguity to the Consumer and to Subsidiary trades*. Outside these again, are the sufficiency of capital, the restraints of law and custom, and the artificial support of subsidies, bounties, or protective duties. While most of the above points have a permanent relation to the country and locality under consideration, some of them are liable to possible changes in the future which should be held in view. In comparing the respective advantages of different countries in regard to some branch of manufacture which is carried on in both, it is necessary to consider separately these various circumstances if any useful conclusions are to be arrived at; and especially is this necessary where the peoples who are concerned have much in common. In regard to the iron and engineering trades, an example in point would be afforded by a comparison between Great Britain, and either France, Germany, Belgium or the United States. Between nations such as these, of the first rank in manufactures, though one or other may be slow to adopt improved methods, the natural process of competition leads in time to all the advantages of science and the inventions arising out of them becoming common property.

Essentials and non-essentials.

Countries, how to be compared

Inventions become common to all.

For a home trade local manufacturers may, if the country permits it, always have an advantage, for by protective duties such a trade may be retained at whatever cost. Local competition will, however, generally arise in trades thus protected, and an export trade is greatly hindered by the enhancement which protection causes in the cost of labour, purchased material and rates of freight for export. Thus, the competition of the United States with Europe in supplying steel and engineering goods in the neutral markets of the world has been hindered and postponed; therefore in regard to an outside or foreign trade, any disadvantages which are peculiar to the manufacturing country will show themselves in the long run. The conditions just alluded to so combine or merge into each other that an exact classification is impossible, and in the following remarks it is only attempted to draw attention to some of the more important points which should be considered by those who contemplate such undertakings. Where factories of whatever kind are already established in a locality, the conditions of profitable working are sufficiently known or may be ascertained by those acquainted with the trades in question; and when failure occurs it generally arises from an attempt to compete in goods where the supply is already equal to the demand; from insufficiency of capital or an expenditure of capital excessive for the purpose in view; from a non-appreciation of the examples available for imitation; or from bad management. Where a new industry is to be introduced into a country or district for the first time, the risks are enhanced by the want of precedent.

Home trade may be retained.

But foreign trade is open to rivals.

Causes of failure.

Risks of new undertakings.

In newly-settled countries with suitable natural resources, there are, generally, enterprising men who desire to establish factories for the manufacture of goods which may have been hitherto imported; and there is a natural desire on the part of the community to encourage such a national trade. There are some manufactures which should obviously be taken in hand; for instance, no people would—if they could help it—remain absolutely dependent on a foreign supply of munitions of war; therefore arsenals, dockyards and factories, whose primary purpose may be for the production of warlike stores or effecting repairs, gradually find profitable employment in new work also. It may be assumed that in every inhabited country there are natural advantages which have caused it to be populated; fertile lands or abundant minerals being those on which the early prosperity depends. In such countries a busy people can produce much

Manufacturers in new countries.

Necessary trades.

Natural advantages.

more than they can consume, and an export trade which brings back from older countries manufactured commodities of all kinds for the necessities, comfort, or luxury of the people, is naturally developed, which, to the thrifty and successful, allows an accumulation of capital which is the basis of all manufactures. Assuming that a demand for certain commodities exists or may be reasonably expected, the trades most likely to succeed in a new country in competition with imported manufactures are those which are simple and self-contained, and are least dependent on subsidiary trades. The natural tendency in manufacturing operations is towards a subdivision of processes by which workmen, continually engaged on repetition-work, and assisted by special tools, can produce their goods well and cheaply. This tendency finds its greatest development in an old country, and any attempts to rival such well-organised and minutely-divided industries will, under less favourable circumstances, have small chance of success. For instance, in a colony or newly-settled country, where coal and iron, hitherto unworked, are found in close contiguity, it would appear as though finished iron or steel might be produced more cheaply than it could be imported; there is, therefore, a natural desire to encourage such local manufacture. These local materials will have their value in the future, though government interference with their development, except by the granting of facilities or the removal of obstacles, may involve considerable risk to the true interests of the community. Thus, if preference were shown to a local industry in order to induce the establishment of factories when the economical conditions were against them, the country would find itself saddled with an unprofitable undertaking; and bounties, subsidies, or protective duties, when the real conditions were revealed, would be demanded or perpetuated with all their attendant evils. In the older country the processes would probably have been so cheapened by subdivision, by special appliances and by the magnitude of the operations, that the cost of production, even including the expenses of transport to a distance, would, most likely, have been brought much lower than the new country could for a long time hope to rival. To make steel, steam-engines, or cutlery in a newly settled country would generally be unprofitable, even though raw material of every kind were abundant. Rather, therefore, should the tools and appliances which, by years of accumulated experience, have been brought to perfection and cheapness in the old country, be utilised for those trades and processes which are primary and simple in the new.

Trade developed in new country.

Simple trades best.

Subdivision difficult in new countries.

Utilisation of local materials.

Premature development of manufactures.

Imported goods cheapest.

Instances.

See also page 469.

Bounties.

Native industry is sometimes encouraged by bounties on production instead of by taxes on imports. This is really a cheaper and more logical application of the protective principle; for such bounties, being paid directly out of national funds, instead of, as in customs revenue, by indirect taxes not so palpable to the consumer, the amount expended may be exactly calculated, and the indirect losses incident to such taxes are not incurred by the community.

Other hindrances to trade.

Jealousy of foreigners.
See page 54.

Tenure of Land.
See MINING, *page* 54.

Government interference.

Concessions.

See Chaps. II., III.

Monopolies.
See page 28.

Sometimes necessary.

See page 38.

There are other ways than those just described by which the natural course of trade is hindered. The protective system, erroneous as it may be, is, at any rate, intended to encourage national manufactures; but in some countries new enterprises are actually and sometimes even directly discouraged by the laws and customs which prevail; and especially so when such enterprises are introduced by foreigners. Very often, opposition to all undertakings introduced by foreigners, or which tend to alter existing methods, arises from jealousy on the part of the ruling class, and none the less because it may be unavowed. In some cases peculiar laws or customs concerning the tenure of land, hinder the exploration for minerals or prevent their economical treatment. In other cases, taxes specially directed at the new enterprise may be imposed without warning; or, where permission to utilise the products of the country depends upon the will of some sovereign ruler, a sudden or new decree may have the effect of confiscating the capital already embarked. Even in countries where there is a semblance of justice in these respects, government interference often acts as a restraint. For instance, the right to trade or manufacture, sometimes depends on licences or concessions, the price for which is—all or part—a source of revenue to dishonest officials or persons of influence. The price thus paid for what may really be a mere permission to benefit the country, loads the undertaking from the commencement, and still leaves the risk of competition from another successful application by similar means; while, on the other hand, if not only permission, but monopoly be granted, the community is taxed. There are of course undertakings—such as tramways, waterworks, electric light and power works, and gas-works—which must to some extent be monopolies, and in the profit of which it is right that the community should share; though it would generally be better if such a share lay in the conveniences afforded, low tariffs, or the reversion of the property after a term of years, rather than in a money contribution to the public revenue. In some cases trade

Restraining laws. is much injured by vexatious restrictions, even though these may be of a petty kind. For instance, onerous laws as to master and workmen, undue responsibility on the master's part for accidents, taxes on materials or on revenue, may exist, and not only so, but have, often, to be secured by heavy sureties or money deposits. Hindrances such as these may harm the community for the advantage of a few; and experience has proved that, in regard to industrial undertakings, a government acts best by interfering as little as possible. **Philanthropic restraint.** *See also page 2.* In Great Britain there are laws which are none the less in restraint of trade because enacted for the public good. The Mines Regulations Acts, the Compensation for Accidents Acts, laws as to hours of labour for children or for the enforcement of education, and limits as to the loading of ships—all these, in the first instance, increase the expenses of production and delivery. **Ultimately advantageous.** But it cannot be doubted that such laws, wisely applied, will so increase the comfort or intelligence of the workmen as to fully balance the apparent loss.

Obstacles sometimes arise from the method rather than from the amount of taxation. **Vexatious excise laws.** Thus manufacturers are greatly hindered in some countries by taxes so imposed as to require, to prevent evasion, constant inspection and regulation of processes. In Great Britain the numerous taxes of this kind which formerly existed, and which required a costly and complex administration, have been almost all abolished, with a gain to the community far outweighing the taxes sacrificed. **Instances.** Paper and glass afford conspicuous instances, for these industries, when relieved from the inspection and interference of the excise officers, became greatly extended, and better, more numerous, and cheaper commodities were manufactured. And, although excise limitations on beer and spirits still exist, they are recognised as evils which are minimised by the nature of the articles taxed, and by that need of revenue which forbids their abolition.

Factories first established for repairs. Engineering factories in countries where such industries are new, and especially factories in seaports, are generally first established for repair work which must be performed locally. Railways, docks, gasworks and other undertakings which are necessarily localised, as well as the steamships frequenting the ports, constantly require the services of the engineering trades; and factories whose primary purpose is to satisfy such wants, find employment also in new work on a small scale. When the natural resources of material and an industrious people are available, manufactures may so increase as at last to entirely supersede the necessity for importation. **Growth of factories.** Trade so established on a natural basis is more likely to prosper than that dependent on subsidies or protection. Manufactures are encouraged in some countries by the granting of a monopoly to whoever will inaugurate a new industry; and a justification of such monopolies may to some extent be based on the same grounds as justify the patent rights granted to inventors, for an entirely new industry is somewhat of that character. But though expediency may in some cases excuse the granting of monopolies to encourage the investment of capital, trades so fostered are seldom of real advantage, and the evils of the system outweigh the supposed benefits. Government aid may be granted also by guaranteeing for a few years a revenue to some new industry which is obviously needed, but which, because of its novelty, may not without some such guarantee tempt capitalists to venture. But, as already stated, that legislation is of the best kind which, avoiding all possible interference, is directed only to the removal of obstacles, thus giving greater freedom for enterprise.

Exclusive rights granted.

Government aid. *See page 29.*

Obstacles removed. *See page 26.*

Climate has to be considered in certain trades, since extreme heat, cold or moisture may render processes carried on successfully elsewhere, difficult or expensive or unprofitable. An iron or steel industry situated in a country where the hours of labour are lessened by seasons of extreme heat, is obviously at a disadvantage with others not so hindered. On the other hand, in countries subject to intense frost, all operations depending on a water supply or the flow of water through pipes are liable to stoppage. Again, extremes of climate tell injuriously where workmen are brought from a distance into surroundings to which they are unaccustomed. As climate largely determines the kind of buildings and the arrangements which may be necessary for heating, lighting, and ventilating, a factory should be designed to meet the prevailing exigencies of the seasons, such as heat, cold, rain and wind. Any precautions which are usual in the locality to meet these conditions should be investigated, and if expedient, imitated. Too often, however, it does not occur to those who are familiar with these circumstances to describe them to the engineers at a distance whose aid they may seek for designs and projects. Sometimes the climate may render special artificial warming or ventilating arrangements necessary, and in all matters of this kind the comfort of the workmen is in the true interests of the employer. In a climate where extremes of temperature—as in Great Britain—or frequent rains, hinder out-of-door work, the covering in of open spaces may prove a remunerative capital investment. Work-

Climate.

May hinder manufacture.

Or injure workmen.

Buildings must be suitably designed.

Precautions taken.

Out-of-door work hindered.

Advantages of proper shelter.

Showy buildings to be avoided.

Building materials.

See page 74.

men will obviously work better when protected from unsuitable weather; and the saving must not be measured merely by the hours in which work would otherwise be hindered, but by much indirect gain, as the current or standing charges of a factory continue, even though the work be stopped; and after a stoppage, much time is often lost in starting again. If all the men do not return together, groups of men dependent on each other may be rendered useless by the absence of one or two. The warming of workshops in winter before the men arrive in the morning is advantageous to the proprietors, and outlay may be better bestowed for such purposes than on showy buildings or expensive offices. Unless in a retail trade, purchasers are little influenced by such supposed attractions, and simple offices suitable for their immediate purpose are in better keeping with the object of a manufactory. The design for a factory obviously depends largely on the building materials available in the locality, and the reasons for or against importing particular kinds of material should be carefully considered.

Choice of locality.

Contiguity to materials.

See IRON, *page* 387.

See COPPER, *page* 366.

See page 449.

The choice of *Locality* depends mainly on the contiguity to materials, on the cost of transport, on the abundance of labour and on contiguity to the consumer. Taxation and other public burdens have also to be considered; for these vary in different localities, and in some cases it is cheaper to establish a factory outside a certain district or town. The importance of contiguity to suitable materials depends on their weight or bulk, the cost of carriage, and the proportion which this bears to the whole cost of production. Thus, in the ruder operations of the iron trade, such as smelting, if the coal and ore do not lie together, the necessity for carrying one or both long distances to the furnaces might entirely forbid the trade, unless the carriage was, by means of water communication, cheap, or unless still greater difficulties intervened to prevent a delivery of iron from abroad.

Materials must be of proper kind.

Steel an example.

See STEEL, *page* 557.

See IRON ORE, *page* 383.

Materials must be of the kind exactly suitable, as the application of scientific processes to manufacture which is constantly going on prescribing standards of comparison and quality cannot be ignored. Thus in the manufacture of steel, not only coal and iron ore are needed, but special kinds of each; and even in countries where coal and iron abound, some part of the materials may have to be brought from long distances. All the countries which make steel by the modern processes have to seek far and wide for suitable ore, and the cost of carriage from the mines of Spain and other Mediterranean

Contiguity to material sometimes unimportant.

countries which furnish supplies to Europe and America is an important item in the cost of production. In trades where the material bears a small proportion to the total cost, distance matters little, if other circumstances are suitable; and a maker of cutlery and firearms is not—other circumstances being favourable—weighted much, even if the iron and steel be brought from a distance.

Facility of transport.

Roads and bridges.

See pages 26 *&* 133.

Transport is an important incident in most manufactures, not only for the raw material, but for the finished products; and, as just stated, an industry otherwise feasible and desirable may, for want or such facilities, be rendered entirely impossible. Except in the most primitive countries, where each district provides for its own wants, inter-communication is a necessity; and next to the maintenance of law and order, it is the first duty of a government to promote the construction of roads, bridges, and harbours. Instances are numerous where countries, highly favoured by nature and having abundant minerals, fuel, and water-power, are practically standing still for want of means of communication. For instance, when such countries border on the sea, manufactured goods which might be produced at home are brought from foreign countries and delivered within a short distance of the inaccessible native products. It follows, therefore, that a government will do more real good to its country by removing such disabilities than by giving to its handicapped industries the artificial stimulus of protective duties or bounties.

Water carriage cheapest.

See page 352.

See EXPORT, *page* 445.

Canals.

Sometimes costly.

Where speed in transit is not esssential, water carriage is the cheapest and best; hence, navigable rivers are one of the greatest natural advantages in any country. Goods once embarked may be carried long distances for a tithe of the cost of road or railway carriage; and in the case of bulky, heavy, or fragile goods, the risks of carriage are generally less. Even for an inland trade, canals can compete with railways in the cost of carriage, but they can seldom be constructed profitably except in level countries, for numerous locks not only involve large capital expenditure, and delays in transit, but increase the cost of maintenance and working.

Factories on main routes.

Return cargoes cheapen carriage.

See page 353.

It is obvious that, for any but a local trade, factories should be situated on the lines of communication, because even where the manufactured goods are for local use only, the raw materials may have to be brought from a distance. The cost of carriage by land or water depends greatly on there being goods to carry in both directions, this being one of the numerous advantages of the free exchange of commodities. Thus, when iron ore and coal are 100 miles apart, the vessels or railway waggons taking ore to the coal may bring back coal to the ore. Trades utterly dissimilar may assist each other in this way, and, indeed, allow an otherwise impossible profit by reducing the cost of carriage.

Cartage.

Cartage may be saved by building a factory immediately on the railway, canal, or river which serves for transport; but while, for engineers or others dealing in heavy merchandise or materials, the point is of importance, in other cases the convenience offered should not be over-estimated nor allowed too great a weight against the opposing advantages of another site. The proportion which the expense of cartage bears to the total cost of production and delivery differs, of course, with the nature of the trade, and while an ironmaker or a bridge-builder may economise by bringing in coal and iron, and loading up goods directly on to a railway truck, canal-boat, or ship, a manufacture of machine-tools or small steam-engines might, if the general advantages of the railway or canal are present in the town or district, find no sufficient inducements in a saving of cartage to draw him from an otherwise desirable site. A railway siding at a factory often enables a manufacturer to load and pack his goods more carefully or systematically than would be feasible at a common railway station, and, in the case of heavy goods, to utilise special cranes of the factory which do not exist at the station. Railway companies, however, do not always allow a reduction of charges corresponding to the duties of which they may be so relieved.

Railway sidings save cartage.

Advantageous in heavy trades.

But may be over-estimated.

Facilities for loading.

See CRANES, *page* 787.

Carriage by sea.

For a foreign trade, contiguity to the sea and means of transport are of great importance; and it is to these advantages, as well as to the possession of iron, coal and skilled labour, that Great Britain owes her success against foreign rivals. Frequent transfer and transshipment are not only expensive, but involve risk and damage; the minor charges in these respects often exceeding the actual cost of transport. Vast outlays on docks, jetties, sidings, cranes and other facilities for shipment, greatly reduce the expenses of the manufacturer and the merchant, and in the countries which possess these advantages much assistance is rendered to traders in the competition with even superior natural resources in other countries.

See SHIPMENT, *page* 445.

See HARBOURS, *page* 116.

Contiguity to the consumer may outweigh other advantages.

Contiguity to the Consumer is sometimes of greater importance than contiguity to the material, for the convenience to the purchaser of ready conference with the manufacturer, of speedy delivery, and the facilities afforded by local factories for after repairs, may outweigh the mere saving in money which purchasing from the more distant manufacturer might allow. This is illustrated by the example afforded in the manufacture of agricultural implements. The manufacture of these goods has been largely confined to districts where they are used and purchased, and where a general engineering trade would be a failure. So, also, shipbuilding may prosper at commercial ports not so well favoured in regard to contiguous materials as other and more remote places. In great cities, or centres of population, trades may generally be found which, though not favoured by circumstances generally deemed essential, have grown up to satisfy a local want. Trade in second-hand or waste material generally flourishes in a large city; and, among the trades which thus arise, that of re-working and rolling scrap-iron, or the utilisation of by-products from gas-works may be instanced.

Trades congregate.

Second-hand trades. *See page* 250.

Labour is a primary necessity in all manufactures, and skilled workmen may generally be best obtained in localities where there is a congregation of similar or kindred trades, as numerous factories create a good labour market, and induce workmen to seek employment there. Such a congregation of factories also brings purchasers to the locality. New countries are at a disadvantage in this respect.

Labour.

Workmen congregate at trade centres.

Contiguity to Subsidiary trades is sometimes of more consequence than at first appears. Thus if a Birmingham gun-factory, a Sheffield cutlery works, or a Nottingham lace-mill, could be transported with all its workmen to a district where materials were plentiful and there was a brisk demand for the commodities, they might fail for want of the preliminary trades which perform exclusively, and therefore cheaply, the earlier processes with the raw material. They might also fail for want of the adjunct or contributory trades for repairs and renewals; and for want of the various minor purveyors who surround the numerous similar factories in the original district or country, but which a single factory could not alone support. In other words, this subdivision of labour requires a large trade and a busy population: thus industries needing such contributory trades are difficult to transplant.

Contiguity to subsidiary trades.

Contiguity to Fuel or to Power may be absolutely necessary if competition with rivals similarly favoured is to be successful. The coal for steam boilers may be of such primary importance as to be classed as a material of manufacture, and for metallurgical processes may entirely determine the suitability of a locality. The *kind* of fuel which can be obtained, as well as the abundance of it, is thus one of the numerous circumstances to be considered. It may

Contiguity to fuel or power. *See Chap. XVIII.*

See COAL, *page* 529. *See* GAS, *page* 482.

The kind of fuel.

See ENGINES *and* BOILERS, *page* 571.

be advantageous to erect gas-producers by which the calorific qualities of coal can be better utilised than if used direct. The improvements in large gas-engines, and the facilities by which cheap producer-gas can be applied to metallurgical purposes, or even as fuel to steam boilers, justifies the intermediary process.

Water supply.

Quantity and quality.
See WATER-WORKS, *page* 192.

Water for condensing-engines.

Potable water.

Supply and storage.
See PUMPS *and* TANKS, *pages* 613 & 639.

Water is necessary to most trades, quantity being important in some cases, as for washing ores or making paper; quality in others, as for brewing, bleaching, and dyeing; while in others the pressure from elevated reservoirs or from rapid streams is valuable for power purposes. The life, or durability of steam boilers depends greatly on the kind of water which is used; and if it be very "hard," or impregnated strongly with lime, the steel plates deteriorate much more rapidly than with "soft" water. But it is possible to minimise the evil by a special construction of boiler, and therefore the facts should be known to the engineer who designs the machinery. Water, besides that for boilers, is needed for condensing-engines, and if the supply be limited, it may be expedient to store that discharge from the engine in a pond or tank, for re-use; while if only salt water be obtainable, surface-condensers are necessary. A supply of pure and cool drinking water for the workmen not only adds to their comfort, but tends to their sobriety. On the source of the supply the necessity for wells and pumps depends; on the abundance of the supply and the liability to drought or scarcity, the kind, number, and position of storage tanks. If the water is to be derived from public works, the head or force in the mains, the price and terms at which the water is sold, and any limitation to its free use, should be fully known and considered at the outset. The position of contiguous water mains, or other existing source of supply, should be ascertained and delineated on the building plans.

Gas for lighting.
See GAS-WORKS, *page* 235.

Power utilised for lighting.

Electric light.
See page 254.

The supply of *Gas* or Electricity for lighting should be considered; and if there be no public supply it may be expedient to construct special works, and the arrangement of these must be embodied in the design. Advantage may be taken of the motive-power of a factory for Electric Lighting purposes; or the blast provided for melting-furnaces or smiths' fires may be applied to crude-oil lamps; where power is not available, portable self-acting lamps, which automatically generate their own blast, may be used. This latter system affords a cheap and brilliant light for outdoor operations.

Choice of site.

The choice of a *Site* must be determined partly by local circumstances, and partly by the nature of the trade; and great care is requisite not to exaggerate too much the importance of one set of incidents to the exclusion of the others. The value of land for a factory depends, of course, on its position in regard to a town, and to the means of communication; on the soil, and on the tenure. A freehold site is esteemed everywhere; but there are few countries where the peculiar conditions which are common in England in connection with leases, titles, and restricting covenants, apply with equal force. The agricultural value is generally the primary measure of price, and land of low value in this respect may frequently be obtained cheaply for building purposes. Suitability of the substratum for the foundations of the buildings is a matter which depends on the kind of buildings it is proposed to erect and on the nature of the trade. The condition of the site in these respects should be known to the designer, and he should also know whether it is already cleared, levelled, or drained. If the site is drained, or if there be any system of drainage established in the neighbourhood, information concerning it should be furnished, and noted on the plan. A loose soil may involve great cost in foundations, whilst a damp soil may be unsuitable for furnaces, boilers, or foundry pits, and need expensive adaptation. On the other hand, considerable expenses for adaptation may be justified by special causes; as, for instance, where the advantages of a river frontage may warrant considerable outlay for pile-driving, embankments, or wharfs. The placing of a factory on marshy or undrained soil, or on a river bank, may render certain operations of manufacture difficult or impossible. Certain kinds of castings require pits below the ground level, and if these are liable to be flooded, expensive iron lining to the pits may become necessary.

Value of land.

Freeholds.

Measure of price.

Suitability for foundations.

Drainage.
See page 208.

Expenses of adaptation.

Objections to undrained soil.

A site otherwise desirable may be rendered useless for want of workmen's houses; and if these have to be built specially, the capital expenditure becomes greatly increased. It is expedient sometimes in the case of certain trades to choose a locality remote from a town, so that labour, materials, power, or other necessary commodities may be obtained cheaply; but skilled workmen not infrequently dislike factories remote from large towns, and prefer places where comforts and amusements are more abundant. An expenditure for workmen's houses often proves a profitable investment; but if the houses depend entirely on the new industry for tenants, a heavy pledge for its continuance is added to the general risks. In the vicinity of large cities like London or Glasgow, work-

Workmen's houses.

Prices of food and clothing.

Capital spent on houses.

Cheap trains.

men's trains at very low fares afford the same convenience as do cheap houses near the factory. Not only houses, but cheap food and clothing reduce the cost of labour, and these advantages are best obtained by allowing freedom of commerce to the various traders who will come forward to supply a demand.

Cost of living reduced by free trade.

Capital outlay.

In establishing a factory, one of the primary considerations which must be kept in view throughout the design is the *Capital outlay* and the proportion it will bear to the probable revenue. Many of the most profitable industries have grown up piecemeal from very small beginnings, every fresh extension being justified by a pressing need and guided by a preceding experience. A manufacture so established is, however, often greatly hindered by the want of order and arrangement in the various parts or processes; and a succession of additions and attempted improvements sometimes culminates in an entire rebuilding of the factory. It is not unnatural, therefore, that capitalists, in establishing a new factory, anticipate high profits because of the improved plans they are adopting, and on the fact that they benefit by the accumulated experience they find available. The ingenuity which suggests all these arrangements may, however, be a cause of positive loss instead of profit. So much money may be laid out on railway sidings, special machinery and other facilities, that, unless a large output can be maintained, the load of capital swamps the entire undertaking. In the desire, therefore, to have every arrangement perfect, there is risk of incurring an expenditure which may really prove unremunerative, even though the outlay has been for labour-saving processes. Factories so established may, however, eventually repay those who can afford to wait; but without a large trade the burden of capital, especially if some of it be borrowed, is a frequent cause of failure. Ultimately the profit is reaped by those who take advantage of the failure to buy the factory for much less than it has cost; and instances are not uncommon of a second or even a third change of ownership taking place before the capital can be brought down to a sum on which the earnings will show a profit. Cases of this sort mostly arise when a period of prosperous trade encourages the extension of factories, which attain completion only when a reaction has set in and trade has become dull. The current rate of interest is the primary standard by which the sufficiency of profit must be measured: the prospective profit necessary to induce an investment of capital in manufactures being determined

Want of order in old factories.

Expenses of re-adaptation.

Improvements may cause loss instead of profit.

Excessive capital a cause of failure.

Change of ownership becomes necessary.

Rate of interest on money.

Low interest advantageous.

Depreciation. *See* WORKSHOPS, *page* 770.

by the risks and trouble of the particular trade in question. In newly-settled countries, the current rate of interest is much higher than in Great Britain, where spare capital is abundant for those who have inducements to offer. This high rate of interest for money is therefore as much a disadvantage in international competition as dearness of material, labour, or any other necessary commodity. The depreciation of buildings and plant must also be taken into account, and the temptation to treat as profit the surplus of income over expenditure, without sufficient allowance for depreciation, resisted. The circumstances that must be considered in "writing off" for wear and tear and other causes are various, and no fixed rates can be established till all the circumstances are known.

Order of procedure.

Laying out of factory.

Sequence of operations.

Haulage and lifting.

See CRANES *and* LOCOMOTIVES, *pages* 787 *&* 691.

Ground floor and upper stories.

Advantages of upper floor.

The Order of procedure in the processes of manufacture, and provision for after-extension, are two circumstances not always easily reconciled in preparing the plan of a factory. The first may be considered as of the more immediate importance. In dealing with heavy materials which have to be treated in many departments, the cost of manufacture and the general economy of the factory greatly depend on the arrangement of the various workshops, so that the proper sequence of operations may be observed. It is thus desirable to avoid, not only unnecessary carriage, but unnecessary lifting also. Goods from factories on high ground can be despatched down-hill to a railway or port very cheaply, while if on low ground, the material may be brought down-hill to the factory. In favourable cases, the empty waggons can be drawn up by the descending loaded waggons. In some factories it is sought to bring in the materials on an upper story, and to let them descend by their own gravity through the various workshops and processes to the ground, so that the materials may be taken in at the higher level and carted out at the basement. Hoisting may, however, be so cheaply and expeditiously performed by the various modern appliances, that too much importance should not be given to plans for avoiding it; and the same consideration applies in estimating the advantages of a two or many-storied factory, as compared with those of one where all the processes are carried on on a ground floor. Although in special cases, such as an iron-foundry or smelting-works, a ground floor is alone suitable, there are often positive advantages in working on an upper floor. Light and air may be better obtained; the workmen are less disturbed by other operations, and may be kept under better control; and there is also the obvious saving in the area of land required. Travelling-cranes and

Modern facilities. hoists, as usually available in modern factories, allow of plans and workshop arrangements of a kind formerly impracticable or too expensive. On the other hand, where land is abundant, and there appear advantages in working upon the ground floor, the cost of handling and moving materials and goods must not be measured by the distance, but by the facilities obtainable for carriage. **Tramways.** Tramways allow heavy or bulky articles to be moved easily and cheaply; and, unless there be some special advantages obtainable by connecting to lines of railway outside, narrow gauges are best. **Narrow gauges.** *See also page 60.* From 10 inches to 15 inches gauge will suffice for a warehouse, and 18 inches to 30 inches gauge for an engineer's factory, these latter dimensions allowing the use of locomotives. For the purposes of a factory, such a line may even be laid with advantage between the rails of a standard-gauge railway already established for outside communication. **Comparative cost of hoisting and haulage.** On the whole, however, hoisting is cheaper than horizontal carriage, though in both the cost depends, not merely on the distance traversed, *See page 798.* or even on the bulk or weight of the articles, but on the number of times they have to be handled or attached to the moving power.

Subdivision of trades. The design of a factory depends, of course, on the nature and extent of the proposed industry. The preparation of the raw material, and the manufacture of it into articles of utility by other persons who purchase it, are a main division which prevails in almost all manufacturing trades. Thus, for instance, the smelting of iron and the **Primary trades.** rolling of steel plates are generally maintained as trades quite separate from those of the founder or bridge-builder. Even where by general rule or custom such a separation of work prevails, there is often a tendency towards a combination of the two manufactures; **Tendency towards combination of trades.** and though the expediency of such a combination must obviously be determined by the merits of each particular case, there are certain main principles which—in varying degree—apply to almost all cases. The subject has to be considered from the point of view of the manufacturers of the finished article, who wish to produce also the material which they have hitherto purchased; and from another view, in the interest of those who have confined their attention to the production of such material, and who wish to enter upon the final manufacture also.

Supposed saving of intermediaries. In the struggle of competition, and in the desire to economise at each stage of production, the manufacturer may be led to undertake the earlier processes with the idea of saving an intermediate profit which may allow a sale of the finished commodity at lower prices than rivals can afford; but this is, to a great extent, fallacious, for the capital employed in a really distinct function should earn its own profit; and it can hardly be expected that the earlier processes will be cheapened under inexperienced or deputed management. Sometimes, even where the burden of the additional capital is fully recognised, a larger or more easily earned total profit is the object still in view. The vicissitudes, risks, and difficulties of an accustomed trade are well known; but the earnings of another's trade are more apparent than the dangers or the drawbacks which belong to it. The maker of the raw material, which has to be sold at exactly regulated market rates, sees that the finished commodity is sold at prices not so strictly defined, and which, in ignorance of the actual conditions of manufacture, he may consider very profitable; while, on the other hand, the maker of the finished goods, who has generally more varied difficulties to encounter in his proper business than the first from whom he buys his material, is, on his part, tempted to enter upon a trade which appears to be simple, easy, and profitable. A maker of the first material is sometimes reluctantly compelled to enter upon the secondary or finished trade to find an outlet for his products; but if these cannot otherwise be disposed of, the fact generally implies a slack or fluctuating demand for the finished commodity also. One of the best justifications for establishing a factory to furnish the material which it would be more usual to purchase, is where there are actual circumstances, such as distance, or lack of competitive sellers, rendering a regular supply doubtful; or where it is important to have materials of high or peculiar quality which cannot otherwise be ensured.

Additional trade requires additional capital.

New risks undertaken.

Mistaken hope of profit.

Combined trades sometimes necessary.

There is often the disadvantage in such a combination of trades, that in dull times the demand for the final products may not be sufficient to absorb the materials prepared for them; and if, to dispose of these, an outside sale is attempted, successful competition with established traders is doubtful. Again the trade in finished products requiring a variety of material, may often be greatly hampered by the necessity of purchasing from one source, and may be at a disadvantage with competitors who are free to select from the patterns or qualities of numerous traders, and who can make available a cheap supply from any quarter. Where aid is sought in the establishment of a new factory, either to design it or to provide capital, the scope of the new enterprise should be clearly stated in

Disadvantages of combined trades in dull times.

regard to the above points, so that the extent and cost may be correctly estimated in relation to the anticipated profits.

Subordinate trade in refuse products.
See GAS, *page* 251.
See COPPER, *page* 366.
See LEAD, *page* 390.
Separate accounts should be kept.

Sometimes a subordinate trade is established for the utilisation of refuse products which would otherwise be entirely wasted; but it would often be preferable if possible, to induce or even assist others to establish such a trade as a separate undertaking. In any case, where two or more trades are carried on together, the costs of the different departments should be so recorded as to show distinctly the burden and profit of each; for if only the general result be known, those branches of the business may be encouraged or extended in which actual loss is accruing.

Tendency toward specialties.

The tendency of trades is towards subdivision into specialties. Thus for use in an engineering factory, not only the material, but all castings and heavy forgings, may be purchased, and neither a foundry nor a steam-hammer be established. Although possibly some profit may be lost in this way, a less amount of capital is needed for plant and appliances; and a manufacturer with limited means, but with a knowledge of his own particular trade, may wisely confine himself to it; at any rate, till he has acquired means and experience to go farther.

Suitability of a factory for its purpose.

The arrangement of a factory depends also on the particular kind or class of commodities to be manufactured. Thus in an engineering works, the kind of machinery to be provided (which will itself be determined by the wants of the local and other trades employing it), or, in an iron foundry, the kind, size and weight of the castings to be made, will do much to determine the kind of buildings, the thickness of walls, the strength of cranes, the width of doors, and other points of importance. In most cases there are accustomed measures of quantity by which the extent or capacity of a factory can be described. Thus, in an iron foundry there is the tonnage of castings of a specified kind per week; in a bridge-building factory the annual weight of structures; in a locomotive or marine-engine factory the number of engines of a certain size that can be erected at the same time, and the total capacity of output per year. This information should be furnished to whoever is consulted about any part of the factory, for the kind and quantity being thus stated, the various processes and departments of manufacture, with the suitable apparatus and machinery, can be designed in due proportion.

Accustomed measures of output.

Extensions anticipated and provided for.

Where a large trade is expected, it is generally sought, in the arrangement of the site and buildings, to provide for future extensions, but it is generally prudent to confine the first expenditure to what will be immediately remunerative. Sometimes it may be sufficient merely to take care in the design that nothing shall hinder such an after-extension; whilst in the other cases it may be expedient even from the first to provide for certain departments or processes of manufacture in excess of the immediate demand upon them. Thus in an engineering workshop, space for a foundry may be provided or enclosed, although its immediate use may not be contemplated; or an erecting-shop may be made large enough, and the overhead crane strong enough, for a heavier class of goods than are at first to be made; for while stronger machine-tools may be easily purchased when the need arises, the alteration of the premises might prove difficult or expensive. If land be cheap, it may be expedient to purchase at the outset sufficient for the probable extensions, although sometimes the cheaper plan of acquiring with one plot of land the right of purchase for a certain number of years of adjoining plots may be feasible. If purchased, the surplus portion may either be let out to tenants on short terms till wanted, or fenced in. Sometimes it is deemed expedient to carry further the preparations for an extended trade. The buildings may be erected, but not furnished with plant. Thus in an engineering factory, shop-space for additional work-benches or machines may be provided at the outset, and utilised merely as storage-room. In such a case the walls and columns may with advantage be made of suitable form and strength for carrying lines of shafting; columns turned for the ready attachment afterwards of cranes or drilling-machines; and in various other ways preparations made which add little to the immediate cost, but which will save much future expenditure.

Ample space provided.

Cranes made strong enough.

Extra land enclosed.

Workshops built but not furnished.

Walls and columns made ready for after attachments.

In deciding upon the expediency of any extension which a sudden increase of trade may suggest, or on the purchase of new plant or machinery for manufacturing some new class of goods for which a demand has arisen, the probability of permanency in the new demand must be carefully considered; for capital once invested in such a way is not easily recovered, and a too hasty expenditure to meet an expected augmentation of trade is one of the most frequent causes of disaster. Foresight is necessary in the arrangement of the buildings to ensure symmetry and due accord between the various processes; and to this end the plans should be decided upon only after they have been considered with reference to each department of manufacture. If it be attempted to prepare the plans piecemeal—for instance

Extensions need caution.

Invested capital irrecoverable.

Foresight to be observed.

Unity of design.

to design the buildings and then consider what machinery shall be used and where it shall be placed, and then only to arrange the order of procedure—trouble and loss are almost certain to occur. For example, in an engineering factory it may be found that the buttresses of walls do not accord with the positions of shafting-brackets; that roof beams are not strong enough or properly spaced for shafting hangers; that the light does not enter in the most advantageous way; the doors are inconveniently placed, or too small; that the columns are suited only for their primary purpose of supporting the roof, and that they require, for want of suitable brackets or projections, uncouth additions to accommodate cranes, shafting, or drilling-machines. The positions of important machines, and especially of engines and boilers which may require excavations or foundations, should be considered before the building is commenced, and the engine room and boiler house be made large enough for additional power.

Instances.

See SHAFTING, *page* 512.

Provision for extending.

Where parallel blocks of workshops are erected, land may be left for extending any or all of the blocks endways. Lines of shafting or pipes in the original workshops may be made of size and transmission-capacity sufficient for the ultimate needs.

Designer needs full information.

In discussing the scheme of a new factory, a contoured plan of the proposed site, with neighbouring roads, railways, and canals marked upon it, should be considered; as the shape of the site, its levels, and position in regard to these circumstances, determine the arrangement of the buildings. The direction from which materials will be brought, that in which the finished commodity will be taken out, and the means of conveyance, should also be borne in mind.

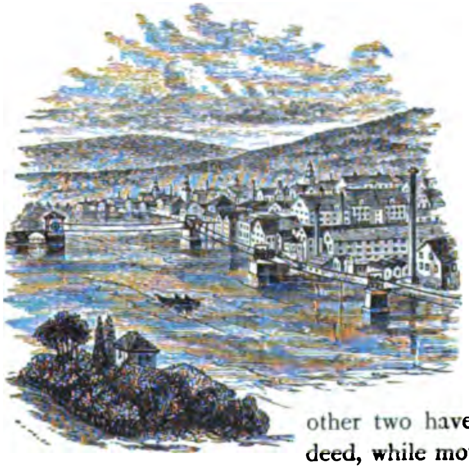
Similar rules apply to all manufacturing trades.

The foregoing remarks have been directed mainly to the establishment of engineering works, and a due regard to the points alluded to is necessary to the proper designing of a factory. But engineers are concerned in the establishment of almost all kinds of factories, where also considerations of a similar kind arise. A proper scheme can only be propounded and a design made, on the basis of full information on every point; and though the varieties of purpose and circumstance in different trades are too many to be enumerated, the nature of the points to which attention is necessary may to some extent be gathered from those which have been given in this chapter for one important industry.

[*See also* TRANSMISSION OF POWER: STEAM-ENGINES: ELECTRIC-LIGHTING: CRANES: MACHINE-TOOLS: BUILDINGS AND ROOFS.]

CHAPTER XIX.

THE TRANSMISSION OF POWER. FUEL. STEAM. WATER. COMPRESSED AIR. ELECTRICITY. CONNECTING-RODS. SHAFTING. BELTING. WIRE ROPE.



THE generation or development, the transmission, and the application of power are three distinct processes which have occupied engineers in all ages. Of these three, however, the intermediate link — the transmission of power— has not received so much attention as the other two have, or as it deserves. Indeed, while motors of every conceivable kind have been the subject of innumerable inventions, and while machine-tools and labour-saving processes have been applied to all branches of the arts and manufactures, the transmission of power from the motor to the machine has, either because it is less interesting, or because it has appeared to be of less importance, been comparatively neglected. Not only is there frequently an unnecessary loss in transmission, but natural sources of power have been entirely neglected because they are situated in remote or inconvenient places, the means really available for transmitting such forces having been insufficiently appreciated. Since 1870 much more attention has been directed to the various transmission systems, both in Europe and America.

Transmission systems neglected.

There is necessarily a loss of power by all transmutations and transmissions, and although, by experiment, it has been ascertained with a considerable degree of accuracy the amount of loss incidental to each system, no mere theoretical comparison is sufficient. For in comparing the respective advantages of the different means of transmitting power, the circumstances to which regard must be had and which will, indeed, determine the choice to be made, are various. First, there is the nature, situation, and amount of the motive power, with which one system of transmission rather than another may accord; secondly, there is the distance to be traversed and the obstacles that intervene, which may render certain methods of transmission unsuitable or impossible; thirdly, the power may either have to be transmitted in the gross or distributed; and fourthly, there is the nature, situation, and extent of the machine or purpose to which the power is to be ultimately applied, and to which one system of transmission may lend itself more readily than another.

Different systems of transmission.

Choice, how determined.

List of methods.

Before attempting to apply these considerations, the various methods of transmitting power may be briefly enumerated as follows:—

Fuel. *See page 481.*

Fuel is the only form in which even potential force can be conveyed from one country to another. Gaseous fuel affords advantages for transmission and distribution over a considerable distance.

Steam. *See page 483.*

Steam, as the most convenient form of developed heat-force, finds its best application in the place where it is generated, and is seldom transmitted far.

Water. *See page 485.*

Water is used for transmitting power in two distinct ways: one, where from a high-level source it conveys the force of gravity; and another, where, as a secondary transmitter, it conveys force given to it by some motor.

Compressed air. *See page 496.*

Compressed Air is used for transmitting force produced by some original or secondary motor. It is available for considerable distances, but it is costly, and finds its chief application where the power-receiving machine is so situated as to render other and more usual methods inconvenient.

Electricity. *See page 504.*

Electricity, as proved and developed by its use for lighting, has become available for transmitting force long distances, where all other methods are impossible, and also for distributing power where shafting was formerly the only available means.

Connecting-rods. *See page 509.*

Connecting-rods are mainly used as parts of a machine, but are used occasionally also for conveying power to a moderate distance, for simple purposes, where merely a reciprocating, and not a circular, motion is required.

Shafting. *See page 512.*

Shafting is seldom used for transmitting gross power for more than short distances, but for distributing power it is more often employed than any other means.

Belting. *See page* 516.

Belting and belt ropes, though they may be regarded merely as adjuncts to shafting, need separate consideration as transmitters, for they are used, not only for distributing power, but—to an increasing extent—for transmitting gross power.

Wire rope. *See page* 522.

Wire Rope is used, not only for distributing power, but for transmitting power for considerable distances in the gross. Since the comparatively recent dates at which wire ropes were introduced their uses have been greatly extended; and there are many situations for which they are better suited than any other means.

Transmission by fuel.

Stored-up force.

Collieries in Great Britain. *See* COAL, *pages* 364 *&* 527.

See page 533.

See STEAM-ENGINES, *page* 571.

Fuel, as the portable embodiment of potential heat-force in that it allows the dormant energy stored up at one place to be utilised for giving motions to machines at a distance, may be legitimately classed among transmitters. The collieries of Great Britain are conveniently situated for shipment of coal, and so great are the facilities for sea-carriage, that it may be transported with advantage to distant countries as a source of power. So cheaply is this effected, that railway traffic in India or South America can be worked almost as cheaply as in England, by means of coal carried 5000 miles. Thus to transmit force to the best advantage, it is obvious that high-quality coal should be chosen, and of a kind that deteriorates the least in stowage and transit, so as best to repay the expenses of carriage common to all qualities. The work of the steam-engine may be included as the last part in the transmitting process, and a steam-engine that consumes only 2 lbs. of coal per horse-power per hour can be worked more cheaply with coal carried half round the world than can a steam-engine in the vicinity of a colliery, where—perhaps because of its abundance—10 lbs. of coal per horse-power hour are consumed.

Mineral Oil.

See OIL ENGINES, *page* 606.

Mineral Oil is likely to take an important place as portable fuel; its use for locomotives and steam ships, where coal is dear, and more directly in petroleum engines, having already proved its fitness. The vast oil wells of Southern Russia are likely to afford an increasing supply.

Coal-Gas.

Coal-Gas, made cheaply in the form of producer-gas, affords a means of transmitting potential heat-force more conveniently and cheaply in certain cases than by any other means. In the direct use of coal there are unavoidable losses recognised by engineers, as

See HORSE-POWER, *page* 570.

Less waste with gas than with coal.

Producer-gas.

Water-gas.

exemplified by the fact that the effective or brake horse-power given out by the best kind of steam engine is, when expressed in equivalent heat units, only one-eighth part of the heat units evolved by the combustion of the coal in the fire-grate of the boiler. When made into gas, not only is this great difference reduced, but the gaseous fuel affords great facilities for distribution and application. In other words it is found that a greater net result can be obtained from the gas made from a given weight of coal than from the coal itself. Producer-gas was first utilised by Siemens and others for the manufacture of steel; the experience gained in steel-works has led to many improvements; and as the gas can be conveniently distributed throughout a works in brick conduits or iron pipes, it has largely superseded the direct use of coal for various metallurgical and chemical purposes. Water-gas, made by the decomposition of steam when brought into contact with incandescent coke, may sometimes be advantageously mixed with producer-gas for certain welding and other processes with iron or steel.

Gas-engines.
See page 602.

The use of gas-engines was greatly restricted so long as high-priced illuminating gas was alone available for them. The substitution of cheap producer-gas about the year 1882 was a great advantage, but lessened so long as gas of a suitable kind could only be made from particular kinds of coal, such as anthracite. By later inventions, suitable producer-gas can be made from bituminous coal, and though it has only about one-fourth the calorific value of illuminating gas, it is cheaper, because it costs less than 2*d.* per 1000 feet (from coal costing 10*s.* per ton). Much even of this low cost is recovered by the value of the residual products obtained, mainly sulphate of ammonia, which is saleable almost everywhere as an artificial fertiliser of land.

The chief uses for gaseous fuel are:—

(1) The melting and re-heating of iron and steel, and for other analogous metallurgical purposes.

Gaseous fuel, how used.

(2) As fuel for steam boilers. Where there are numerous boilers distributed over a considerable area, and where an aggregate of not less than 200 horse-power is required, it is cheaper to utilise the coal in the form of gaseous fuel generated at central producers, and to convey it in pipes to the boilers. By this means also much of the labour of stoking and loss by unconsumed cinders and the cost of their removal are saved.

(3) For rapid combustion or explosion in a gas-engine. Since

gas-engines of high power have proved successful, the advantages of producer-gas for such motors have been still further enhanced.

See page 605.

As gas can be conveyed in pipes with very little loss by friction or leakage, it is available for transmitting power. Generally, its use in this way has been limited to a range of 1000 feet for the purposes above described, but the success with which the natural gas of Pennsylvania has been conveyed for distances up to 50 miles, shows that producer-gas may be utilised in a similar way. When power is wanted at distances up to 5 miles, it may be cheaper to use the gas near where it is made (either as fuel for a steam boiler or in a gas-engine) to operate a dynamo generator, and to transmit the power by an electric conductor. But beyond 5 miles the cost of conveying electricity rapidly increases, and if way-leave for pipes can be obtained, gas could in some cases be more easily and cheaply conveyed for distances up to 50 miles than an equivalent force by electricity.

See page 504.
ELEC. TRANSMISSION

Zinc and other metals having a potential heat-force, which may be developed by combustion or decomposition in a battery, might be included in the present category; but except that zinc as used in primary batteries is alluded to under the head of electric transmission, such substances do not come within the scope of the present article.

Heat-force in zinc.
See page 254 & 268.

The transmission of power by *Steam* is, in the great majority of cases, confined to the few feet distance between a boiler and the cylinder of a steam-engine; and it is obviously advantageous, for many reasons, thus to utilise the power as near to the generator as possible. But there are, occasionally, situations where this contiguity is unattainable; and experience shows that steam can be effectively conveyed long distances. At mines, for instance, boilers above ground supply pumping and other engines more than 1000 feet below; and though the loss by condensation in transit is a difficulty which may render other systems of transmission preferable, this can be met to a large extent. The envelopment of steam-pipes in felt or other non-conductors of heat, is effective in proportion to the care with which it is performed; and, for long distances, elaborate precautions are sometimes taken, by which steam may be conducted 2000 feet with a diminution of not more than 5 lbs. pressure. Steam for the warming of buildings is frequently conveyed long distances in pipes; but though this may afford an example of transmission, it is

Transmission by steam.
Short distance best.
But long distance feasible.
As in deep mines.
Condensation.
How prevented.
Loss minimised.

of course the very purpose of such pipes to give out, and not to retain, the heat.

Engines needed, but boilers inconvenient.

As in machine-tools. *See page* 513, & TOOLS, *page* 735.

Intermittent service.

Pipes become cold.

It often happens in a factory that small steam-engines are required in situations where steam-boilers would be inconvenient, or where their presence would increase greatly the rate of fire insurance. Moreover, a special attendant, who would not be required for an engine, is needed for a boiler. Machine-tools, whose distance from the main shafting of a factory, or whose great size, renders transmission of power by shafting inconvenient, are often fitted with a separate steam-engine which may, under certain circumstances, be advantageously supplied with steam from a distance; especially where the machines are only occasionally worked, and where, therefore, the maintenance of pressure in a contiguous boiler, or the time occupied in raising steam, would be wasteful. But the intermittent nature of the service required, which may render the maintenance of heat or high pressure in a contiguous boiler inconvenient, is, on the other hand, a direct cause of loss when steam is brought from a distance. For, however well the pipes may be enveloped, they become in a short time, when the connection with the boiler is cut off, as cold as the surrounding atmosphere; and therefore, though the pipes, when once thoroughly heated, may conduct the steam with but little loss, there must necessarily be considerable condensation, and therefore unremunerative consumption of fuel, each time the steam is admitted to them after a stoppage.

Sale of steam to users from central boiler.

Distribution of heat and power in towns.

There are instances, in English manufacturing towns and elsewhere, of one large boiler supplying steam to numerous tenants of contiguous workshops, whose rent to the proprietor for the room they occupy is made to include payment for steam also. This distribution of steam for power purposes is, however, generally limited to moderate distances, in one block or closely contiguous blocks of buildings. So effectual, however, is the plan of enveloping the pipes in non-conducting material, when properly applied, that steam has been used in New York for distributing heat and power over considerable districts by means of pipes laid under ground. In the year 1888 6000 H.P. was sold within a radius of half a mile from the generating boilers. It was found possible to restrict the loss by condensation to 5 per cent., and although there was an additional loss from leakage, the system has been remunerative at prices averaging about a dollar per H.P. per week of 60 hours. At Exhibitions where steam-power is temporarily required, and in small workshops where steam from central boilers is sold to users, prices approximating to one penny per horse-power hour have been usual. Where, as in New York, there is a great demand for heating purposes as well as for power, there is a good opportunity for transmisson; but, generally, the difficulties which are likely to arise are so great as to render the general adoption of such a system unlikely. Steam-pipes should be kept under cover, and be protected from risk of damage or interference; and it is, of course, necessary to provide suitable traps and outlets for condensed steam. If situated on private property, troughs or trenches below ground may serve, if there be no convenient roof shelter; but if the pipes would have to cross streets or pass along public highways, the attendant risks or inconveniences generally forbid their use. With regard, therefore, to the transmission of steam considerable distances in towns, for distribution and sale to users, although such a system might be feasible where streets are made in the modern manner (as in some London streets and elsewhere), with subways specially contrived for water, gas, and other pipes, the local difficulties and conflict of authorities in towns not so provided would almost certainly be prohibitory.

Difficulties.

Precautions.

Street subways for pipes.

Long distances in towns impracticable.

The modern tendency towards higher pressure of steam than formerly, allows more margin for a reduction in pressure during transit; but the unremunerative consumption of fuel which a reduction implies is none the less. There is always the inconvenience that the loss in transit reduces the dryness of the steam, and increases the liability to priming. The superheating of steam by a second process after it leaves the boiler is directed towards this evil, and neutralises some of the effects of long transit. The question of conveying steam long distances is simplified if, by care in the arrangements, it can be resolved into one merely of expenditure of fuel, against which can be set the conveniences which in any particular case are obtained. The comparisons suggested above are, however, all affected by the advantages afforded by electricity, which are in most cases superior for transmission and distribution.

High-pressure steam.

Superheating. *See page* 581.

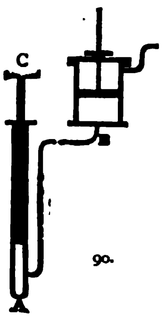
See page 504.

Power can be stored, or concentrated, or transmitted, or distributed, by *Water*; and in many cases more effectively and cheaply than by any other means: some or all of these separate functions being combined according to the purpose in view. For the mere transmission of power, water may be regarded as a long column or rod, which, if force be applied to it at one end, will give out a similar force

Transmission by water.

Water columns or rods.

Power transmitted from steam cylinder.



90.

Method of working.

Advantages afforded.

Water instead of connecting-rods at mines.

See page 509.

See page 492.

ACCUMULATORS.

at the other. Thus, if it be desired to convey the force exerted by steam on a piston to another piston 100 yards or 1000 yards distant, a pipe laid underground from one to the other will perform this effectually. For instance, there may be in or about a factory a hoist too remote from the nearest steam-engine, or the requirements may be too intermittent to utilise its force economically by means of shafting or steam-pipe. The hoist used for lifting pig-iron and fuel to a cupola-furnace is an example. If a ram or piston-rod working in a cylinder A, be placed beneath the platform of the hoist C, and this cylinder be connected by a pipe to a steam cylinder B, conveniently placed in a boiler-house at a distance, and the pipe filled with water, the platform of the hoist may be made to rise by admitting steam above the piston in the boiler-house; and the water in the pipe being pushed forward, in its turn pushes up the ram of the hoist and holds it in position as long as the steam pressure is maintained. By allowing the steam to escape, the hoist falls by its own weight, the water flowing backwards or forwards at each of these operations. Water, though it may be thus compared to a column or rod, has the great advantage over them that it can be conducted even long distances and by tortuous routes without requiring moving mechanism of any kind. The simple method above described was in use in England about 1855, and since that time "hydraulic rods," "water bars," or "water spears," as they are called in different districts, have been substituted in several instances, both in Great Britain and abroad, for the long reciprocating rods so often used for transmitting power in mines. The more modern accumulator system is an amplification of this method.

Fallacies about water-power.

Elucidated.

Weight of a column of water.

There is practically no limit to the distance which power can be transmitted by water, but as a misapprehension frequently arises in regard to hydraulic apparatus, even among those acquainted with other mechanical processes,—such hydraulic machines being sometimes regarded as generators or creators of power, or as capable of evading natural laws by producing great results without a corresponding exertion or without a consumption of already existing force—it may not be superfluous to elucidate shortly the principles involved. A column of water of 1 square inch sectional area weighs nearly ½ lb. for each foot in height, a column 100 feet high weighing 43½ lbs. (43·5 lb.), and if such a column of water were applied to a pair of scales, or to the end of a lever, it would have neither more nor less effect than the same weight of iron, or sand, or quicksilver. The force or power which can be obtained from any head of water, is simply the product of its weight per foot of height (which depends, as stated above, on the sectional area of the conduit), multiplied by the number of feet in height; and if, as in a waterfall or rapid, there be also taken into account the abundance of the supply or speed of flow, the number of foot-pound units affording a measure of horse-power will be arrived at. While, however, a large reservoir or supply pipe will serve for large or numerous machines, it is fallacious to suppose that the power of any one water motor of given size will be increased by enlarging the reservoir or pipe. Such an enlargement would have no more effect than would an increase of boiler and steam-pipe have on the power of a steam-engine with a cylinder of given dimensions. It is the head or height of column and not the area of the supply which determines the power, as will be further elucidated presently in the description of the Bramah press. It is, however, desirable and usual to have the supply pipes of hydraulic machines of ample size, so as to minimise the loss by friction.

Abundance of supply.

See HORSE-POWER, *page* 568.

Power depends on height, not area.

See page 492.

The extreme fluidity of water, which enables it to pass by tortuous routes into the narrowest or smallest place, allows the weight or force of gravity which a column or head of water expresses, to be applied in a variety of ways, and to a degree which is impossible by any other means. Accordingly, engines contrived with cylinder and piston similar to those in steam-engines can be worked by water; but a natural head of water is seldom attainable, and to produce it artificially a steam or other motor for pumping up the water would be required, which, in most cases, would be better applied directly to the ultimate purpose in view. The want of elasticity in water also renders it less suitable than steam for giving rapid piston motion, and the economy which expansion allows in a steam-engine, is wanting. Rotary water engines, therefore, are seldom used except where there is a natural head of water, or one—as in connection with a town supply—provided for other purposes; or where it is desired to utilise power from a distance; or where, for some secondary reason, it is undesirable to use steam.

Water conveyed by tortuous routes.

Water-engines with moving pistons worked by pumped-up water.

Direct steam-power generally preferred.

By means of water the smallest forces may be so accumulated and transmitted as to bring them, with the aid of other transmission systems, into practical use. An instance of such a combination would be afforded where, some considerable mechanical force being needed and neither water-power nor fuel being obtainable, wind was the only kind of force available. Windmills may be usefully applied to pumping up water; and, as is often seen in Holland, they work

Accumulation of power by water.

Wind-power utilised by water.

without attention, whatever be the direction in which the wind is blowing. By such a means, therefore, water could be pumped up to an elevated reservoir; small pumps worked nearly continuously, accumulating a large quantity. The water from the reservoir could be brought down in pipes and applied through the medium of a turbine or hydraulic engine and thence by means of compressed air, high-pressure water, electricity, wire-rope, shafting, belting, or connecting-rods, to the ultimate object in view. Probably by no other means could the fluctuating action of the wind be so well transmuted, accumulated, and applied.

Stored in reservoirs.

Transmitted by various means.

The main pipes by which water is supplied to towns may be, and frequently are, utilised for transmitting power, the force of course depending on the height of the reservoir from which the water flows. There are cases in which water-engines, cranes, and other machines are worked even as far as twenty miles from the reservoir, without the intervention of any other apparatus; and the advantages of a system by which power may be transmitted over hills and valleys, and even across rivers, by simple pipes, are obvious. Hydraulic mining affords an example of pressure water conveyed distances of more than fifty miles. Lines of pipes conveying oil 500 miles from the oil wells to the sea also afford analogous examples. Whether it be remunerative to use water which has been pumped up by steam-power to a reservoir, depends on the cost of fuel for the engines, on the facilities for obtaining power in some other way along the line of pipes, and on other local circumstances. A more favourable case occurs where a waterfall or rapid stream is available for working the pumps without any expenditure for fuel. In such cases, power necessarily localised can be conveyed to a distance, and profitably distributed. The rapid rivers in Switzerland have in this way been utilised by means of wheels or turbines, which pump up water to high-level reservoirs on the neighbouring hills, from whence it descends in pipes, and is supplied for working small water-engines in factories or workshops. There are numerous trades where moderate power is alone required, and where small water-engines of from ½ to 5 horse-power are very useful, as they can be worked at any hour at the will of the user, who pays only according to the water consumed, as measured and registered by a meter on the engine. In Zurich, for instance, water motors are let on hire by the municipality at a rate of 3½*d.* per horse-power per hour. Such a charge, though high if compared with the cost of obtaining power

The water-power in town mains.
See page 198.

Conveyed long distances.

See page 373.

Points to be considered.

Favourable cases.

Natural power.

River-power in Switzerland used for pumping.

Small water-engines.
See page 609.

Cost per H.P. in Zurich.
See also page 525.

from a steam-engine by the expenditure of fuel, is cheap if the convenience of having power always at hand be also reckoned. Moreover, it must be taken in account, in estimating the cost, that the tariff is according to quantity and not according to time only, the net power utilised having alone to be paid for. Not only, however, is the water from the public mains available in the manner above described, but it is used for portable engines also, water-engines on wheeled carriages moving from place to place, being instantaneously connected by hose to a street hydrant, the exhaust water being allowed to flow into the gutter. In this way sawing engines perambulate the town for sawing wood for fuel; and during building operations small water-engines, attached to winches or hoists, are fixed at the foot of the scaffolding for hoisting building materials, the waste water being useful for mortar-mixing or other purposes.

Compared with cost of steam.

Water-power for portable engines.

Power taken from street hydrants.

Small water-engines are driven by water from the public mains in many English towns; small motors, hoists, and cranes being worked in this way at pressures varying from 30 to 90 lbs. per square inch, according to the locality, the abstraction of water for other purposes, and leakage. But the system compares disadvantageously with the more effective accumulator pressure which is now so widely adopted.

Power from street mains in England.

Accumulator system preferred. *See page* 492.

The amount of power which the public mains afford depends, of course, upon the height of the reservoir which supplies them, and the consequent pressure of the water; but, in arranging the water supply of a town, an engineer will be guided by consideration of the pressure which will take the water to the top of the highest houses, or which will afford sufficient force for the jet of a fire-engine, and not that which will permit the conveyance of power for general purposes. A head of water of 50 feet, giving a pressure of 22 lbs. per inch, is the least which would render water engines profitable; for, with a small pressure, the friction of the machine, leakage, and other disturbing incidents, tell with great effect. A higher pressure is therefore much to be preferred; but it is seldom that a head of more than 200 feet is provided in the public mains. A higher pressure is inconvenient for domestic water-supply, as special fittings become necessary, and the risk of loss by leakage or waste is increased. So far do these considerations prevail, that where the reservoir is more than 200 feet above the town, or where there is great difference of level in different districts, it is usual to divide the town into different zones of altitude, and to provide service reservoirs at the moderate height considered necessary for each. Where, however, the source or first reservoir is

Pressure in main, how determined.

See WATER-WORKS, *page* 200.

See FIRE-ENGINES, *page* 633.

Low pressure unprofitable.

Limit of pressure in street mains.

Zones of altitude. *See page* 200.

Power often wasted.

at a greater height than that needed for the domestic supply, and if there be surplus or spare water, it is inexpedient to waste the store of power which gravity affords; and if there be trades which can utilise it, a special main, from the higher level, for water-motors and fire-extinction purposes would be generally advantageous. Pipes strong enough to convey water of 300 feet pressure cost little or no more than those for 100 feet, and even pipes for a head of 500 feet are not very much more expensive unless the diameter be great.

See PIPES, *page* 644

Selling price of water.

Value, how determined.

The selling price of water depends on various circumstances, principally on the abundance of the supply and the cost of obtaining and distributing it. Degrees of softness for washing or manufacturing, purity for domestic use and pressure for fire purposes, are the incidents on which the value of water depends; and it is obviously the pressure by which the value of a supply for power-machines is determined. Water is generally sold to large consumers by meter, 4*d.* and 2*s.* per 1000 gallons being, with few exceptions, the extreme rates which prevail in England; and, unless the capital expenditure has been very large, it will generally be found that a price of 6*d.* affords a sufficient return. Where water is scarce the authorities may refuse to sell it as power; and even if the supply be liable to stoppage in dry seasons, this application of it may, in a manufacturing community, be rendered useless. But where an abundant rainfall affords a more than sufficient supply for most seasons of the year, the expediency of constructing storage reservoirs is worth consideration. Water is used most profitably in those trades—such as paper-making and dyeing—where the exhaust-water from the motor can be utilised for a second purpose. Although a head of more than 200 feet is seldom afforded by town mains, and a natural head of more than 500 feet is generally unattainable, even by special pipes, except in mountainous countries, forces, which such a height expresses are much below those which are best suited to hydraulic machines other than prime movers. And as, with a low pressure, large quantities of water would be required to afford great power, this application of gravity-force is limited in its application. The low pressure may, however, by a simple apparatus, be multiplied for special machines; but it can then only be conveniently applied for a direct action and a short stroke.

Water sold by meter.

See WATER-WORKS, *page* 204.

Seasons of drought.

Storage.

Exhaust-water utilised.

Natural head of water not enough.

See page 494.

Bramah press.

In a description of power transmission by water, the Bramah press almost necessarily finds a place, as it was the first in a series of inventions by which the peculiar properties of water were rendered available. Just as water finds its level by the natural law of gravity, so will water confined in a close vessel, or in a series of vessels communicating by pipes, press equally in all directions; and if to such a close vessel or series of vessels a vertical pipe be attached and filled with water to the top, there will be a pressure on every square inch on all the sides of the vessel of nearly ½ lb. for each foot of height, or, for example, if the height be 1000 feet, the pressure per inch will be 435 lbs. The diameter or sectional area of the pipe or column is of no consequence; it may be 1 inch or 1 foot with equal effect: although, of course, if the sides of the vessel or any movable ram or piston within it begin to yield, so as to give out this concentrated pressure, the smaller pipe will, if not kept replenished, be exhausted sooner than would the larger one. As it is practically impossible, except in mountainous countries (where sometimes water from an elevated source is brought down to the valleys for scouring out the soil under the appellation of hydraulic mining, or for other purposes), to obtain a column of water 1000 feet high, the same effect is artificially produced by loading a plunger, or ram, or piston, so that it presses upon the water in the small pipe connected with the vessel in which the power is required. Bramah effected this by a small force-pump, and the power was concentrated in the larger vessel—a cylinder with a moving piston or ram—with which the pump was connected by a pipe. This is the principle of the hydraulic press, which is seldom now called a Bramah press; and such machines are generally used for giving out great power for a small distance, as for pressing oil from seeds, packing bales of cotton or hay, or for working "lifting-jacks." For such purposes, pressures of from 2000 lbs. to 6000 lbs. per inch are most usual. The apparent paradox thus presented, of small force transformed into great force, is the cause of the misapprehension of hydraulic machines before alluded to. But the apparent multiplication of power—as it is sometimes erroneously considered—should rather be termed a transmutation, for no more foot-pounds of energy are given out than are applied. Thus, if the piston or ram of a hydraulic cylinder have an area 100 times as large as the pump-plunger which supplies it, the force produced, though 100 times as great, will be exhausted when the piston has moved only $\frac{1}{100}$ of the distance traversed by the plunger; or, stated in another way, 2240 foot-pounds on a pump-plunger will give out only 1 foot-ton on the piston. Thus, it is easy in a hydraulic lifting-jack, where perhaps it may be desired to lift 10 tons 1 inch high, to

Laws of pressure.

See also page 486.

High column of water unattainable.

See page 373.

Pressure produced artificially.

By force-pump.

See PUMPS, *page* 623.

Hydraulic presses, how applied.

Usual pressure.

Paradox explained.

See page 486.

Power transmuted not multiplied.

Concentration of force.

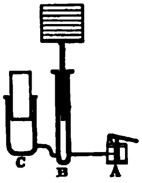
Difficulties.

Leather packing.

exert by a succession of strokes by a lever on a plunger ¼ inch diameter the 1866 foot-pounds which is the equivalent. Bramah was hindered for a long time in bringing his invention to success by the difficulty of making his piston or ram watertight when moving under great pressure; for the ordinary hemp packing used in steam-cylinders, where the pressure is much less, is inadequate for pressures exceeding 1000 lbs.; and he succeeded, through the happy discovery that leather packing, arranged in a peculiar way, would allow freedom of motion and yet prevent the passing or escape of water.

Hydraulic pressure slow.

Accumulator system.



91.

Stored-up power. How applied.

Force always kept ready.

Even at long distance from pumps.

See page 801.

Hydraulic pressure was, for many years after Bramah's time, confined to presses where great force was only required to be concentrated slowly; the process of pumping, to accumulate the small units of force, occupying too long a time for general purposes, unless steam-engines and pumps of great magnitude were provided, the expense of which would outweigh the benefits sought. Armstrong's invention of the *Accumulator*, however, overcame this difficulty, and opened out a wide field for the application of power concentrated and transmitted by water. By the accumulator system the pumps A, instead of forcing water directly into a press cylinder C, are applied to the forcing up of a loaded plunger B, which, in pressing upon the water pumped against it, acts as a substitute for an elevated reservoir. The accumulator is connected also with the machine in which the force is to be utilised; and when communication is open between them, pressure from the falling accumulator is instantaneously conveyed to the machine, and so far as its own stored-up energy will allow, completes the desired operation. If, for instance, a certain operation has to be performed twenty times per hour, lasting each time half a minute, which would require to effect it in that short time a pumping engine of 60 horse-power, an engine of 10 horse-power continuously employed in raising an accumulator will store up the total energy required; or if only ten times per hour, an engine of 6 horse-power will suffice. Or, if, instead of services requiring great power, numerous small operations have to be performed at irregular intervals, the accumulator has always in readiness a force which can be instantaneously applied. The additional convenience that the power can be conveyed long distances—for the accumulator and pumping-engine may be situated a mile or more from the power-receiving machine—greatly increases the usefulness of the system, as is exemplified by its application to the working of cranes, the opening of dock-gates, and the lifting of swing-bridges. At all the modern docks at British ports and at all important railway goods stations, a complete system of transmission is established, affording conveniences more cheaply and conveniently than is obtainable by any other means. The accumulator pressure which has been found most convenient for these services is about 700 lbs. per square inch; equal to a head of water 1600 feet high; this pressure affording sufficient power through the medium of moderate-sized machines, and yet not requiring various special arrangements which pressures above 1000 lbs. would involve. But water of much higher pressure can be conducted with perfect safety.

Usual pressure employed.

See CRANES, *page* 803.

The accumulator system has been combined with that adopted in Switzerland, of conducting high-pressure water through the public streets for sale as power. When the public water-supply in any town is already available as power, it is not expedient to establish another set of pipes for this purpose; but where the public supply is not sufficient in quantity or pressure, the high pressure which an accumulator service affords offers great conveniences in the smaller and cheaper water-engines required, as compared with such engines worked with low-pressure water. This application of the accumulator system is established with success in London, Hull, Liverpool, and elsewhere, where water of 700 lbs. pressure is transmitted in pipes, the power being sold to users at annual rates varying according to the quantity bought, at from 2*s*. to 3*s*. per 1000 gallons, and equivalent to from 1*d*. to 1½*d*. for every 100 foot-tons. Thus, in London, girders and bridges can be riveted together *in situ* without any noise, by portable hydraulic riveting machines deriving power from steam pumps two miles distant.

Accumulator system for public supply.

Advantages afforded.

Examples.

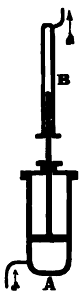
Prices charged.

For working machine-tools, and more especially portable or movable machine-tools, where a great concentration of force is necessary, a higher pressure than that usual with the Armstrong apparatus is needed to allow power-receiving machines of moderate size to be used: and accumulators exerting a pressure of 1500 lbs. to 2000 lbs. per inch are generally employed. For many other purposes for which hydraulic machines are used, pressures of from 3000 to 8000 lbs. are customary; but as power and not speed is the object in view, the pressure is generally obtained directly from the pumps without the intervention of an accumulator. Where a low-pressure system is established for general purposes, the force can be concentrated for special machines; the wonderful facilities which water affords allowing

High pressure for machine-tools.

See RIVETING MACHINES, *page* 762.

Direct pressure from pumps.



92.

Force intensified.

this to be done very simply. A pressure of 1000 lbs. per square inch in one cylinder A, on a piston having an area of 100 square inches, transmitted by a piston-rod to a second cylinder B, called an intensifier, or differential accumulator (the piston-rod acting as a plunger) having only 20 inches area, will be multiplied five times, and water of 5000 lbs. pressure per square inch can then be conveyed to the machine that needs it. Of course the supply, though thus greater in intensity, will be only one-fifth in quantity of that in the first cylinder; but for such operations as testing or punching iron, or for giving a final squeeze of a few inches to a bale, power and not distance is the object in view.

Non-compressibility of water a disadvantage.

Water has no elastic force like steam or compressed air.

Pressure can be maintained.

The non-compressibility of water, by which many of the more important operations of hydraulic machines are rendered possible, and which allows pressure applied to one end of a column of water or hydraulic rod to be given out at the other and distant end, with but little diminution, is a cause of inconvenience in some respects. Directly the pressure from the original source—gravity, force-pumps, or other—is withdrawn, the water is powerless, for it has no self-contained or elastic force of its own, like steam or compressed air. In a steam-engine or compressed-air engine, the supply may be so cut off or adjusted that the steam or air will expand till its pressure is but little greater than that of the surrounding atmosphere; and according as the work to be performed is great or small, the supply is cut off early or late, so that as little as possible of the force may be wasted; but in a hydraulic machine the pressure must be maintained to the end, and if applied to a less purpose than its maximum capacity, the balance of power is wasted. Thus, if a hydraulic-crane, capable of lifting 1 ton, is used for lifting 5 cwt., three-fourths of the power is wasted; while in a steam crane, by cutting off the supply of steam at the proper moment, the expansive force can be more nearly proportioned to the end in view. Improvements have, however, been introduced into hydraulic machines, which to some extent meet this disadvantage. On the other hand, the non-compressibility of water allows a pressure, once given, to be maintained, provided the machine is in good order so as to prevent leakage.

Limit of water pressure.

In theory, the pressure which may be conveyed by water would seem unlimited, but in practice the limit is reached at a point much below that at which metals would be actually compressed. Hydraulic machines in all cases require good material and workmanship, but where the pressure exceeds 6000 lbs. to the inch, the liability to derangement of parts rapidly increases; and although by using specially made machines, higher pressures than 6000 lbs. per inch may be attained, the risk of packing-leathers failing, or of cylinders, pumps, and valves bursting, increases. The cylinders of hydraulic machines subject to these high pressures are necessarily made of great strength, but little or nothing is gained by increasing the thickness of metal beyond 5 inches, as the metal becomes coarse and allows the water to pass through. The area exposed, and the consequent total strain upon the cylinder, increase with the diameter, and therefore small cylinders can endure greater pressure per inch than large ones. For this reason, where great force is needed, numerous small cylinders are employed instead of a single large one.

Bursting of machines.

Thick cylinders.

Steel cylinders are frequently used for hydraulic presses, and steel, compressed when in a semi-molten condition by Whitworth's modern invention, is the strongest material yet discovered. But to utilise a strong cylinder to the utmost, it is desirable to avoid as far as possible applying the maximum pressure to the valves, pumps, and other small parts most liable to derangement. This can be effected in a very simple way by the intensifier previously described, as a pipe may be taken directly from the high-pressure end of the apparatus to the press cylinder, without the intervention of valves of any kind; the pumps and regulating valves being all at the low-pressure end of the apparatus. This method has been used with good results for the final compression of cotton bales, where great density is desired. The great majority of hydraulic machines are, however, worked at moderate pressures, and are not subject to the above risks.

Steel cylinders.

Compressed steel.

See also page 563.

High pressure on valves avoided.

See page 494.

As in cotton presses.

One difficulty connected with the transmission of power by water is the risk of the pipes freezing up during frost. This may be prevented by keeping the water in circulation or, where the quantity is small and little is lost, by mixing glycerine or alcohol with the water. Oil is, under special circumstances and in small machines, used instead of water: it works equally well, and has the advantage of lubricating the parts with which it comes in contact.

Freezing of water.

See page 763.

Oil used instead.

In conclusion, it may be said summarily that power may be conveniently transmitted by water—

Opportunities for water transmission summarised.

(1) Where the power is needed at long or irregular intervals.

(2) Where the distance is too great for steam-pipes or shafting.

(3) Where power, centrally situated, is to be distributed; where it is required for direct and not for rotary motion; and where the exhaust water can be easily disposed of.

See page 487.

(4) Where very small forces can only be utilised by accumulating them—as is instanced by wind applied to the pumping water into a reservoir for use afterwards as hydraulic power.

See pages 759 & 802.

(5) Where great power is to be concentrated, either for such purposes as the packing of bales or for application at different points, as in the cranes at docks and railway stations; or for hydraulic tools.

Transmission by compressed air.

Pneumatic bell a simple example.

Air column or rod.

See HYDRAULIC RODS, *page* 486.

Pneumatic liquid-ejector.

Used for sewage or chemicals.

The Monte-jus.

As in Paris.

See page 500.

Raising of excavated mud from an air caisson.

See BRIDGE PIERS, *pages* 140 & 843.

Compressed Air may be either used as a transmitter for giving out directly at one end of a tube the force applied to it at the other, or it may be used for storing up and transmitting concentrated forces. The pneumatic bell is an example of the first and simplest method—a slight compression of the air at one end of a tube giving out at the other a similar force. The column of air (like the "hydraulic rod" described under the head of water transmission) may be compared to a connecting-rod, with the advantage over the solid rod, that the power may be transmitted by tortuous routes and for longer distances, without intermediate mechanism of any kind. Another instance of direct transmission of power by compressed air is afforded by the pneumatic "liquid-ejector," in which air, forced into a closed vessel and pressing upon the surface of the liquid, forces it up a discharge pipe. This method has, for instance, been applied to the lifting of sewage in low-lying districts. Apparatus of this kind is used instead of pumps sometimes, at chemical works, for raising liquids or semi-liquids which would injuriously affect the parts of ordinary pumps. In sugar-refineries, also, the machine known as a "*Monte-jus*" is an application of the same principle. In Paris, cesspools are emptied by means of the air mains which traverse the streets. This method of forcing upwards by a surface pressure is also shown clearly in subaqueous pier-sinking; for when it is desired in a submerged diving-bell or caisson resting upon the ground, to raise the excavated mud or gravel, it is only necessary to establish by a vertical pipe open at top and bottom, communication with the free air above, and then any loose substance heaped up round the lower orifice of the pipe will be forced upwards by the air-pressure in the caisson derived from the pumps above.

Postal telegraph tubes.

See page 97.

The pneumatic tubes used in connection with the postal telegraphs afford another example of the simpler method; but in these tubes the power, instead of being transmitted to a fixed apparatus, as in a pneumatic bell, is utilised for conveying objects from one end of the

For transmitting written messages.

Description of pipe.

Where used.

Pneumatic underground tramway in London.

Method of working.

Atmospheric railway.

tube to the other. It has been found more convenient in large towns, to transmit messages in writing from the various receiving offices to the central station than by electric-wire signalling. Tubes of lead about 2½ inches internal diameter, encased in iron pipes, are laid beneath the paved foot-ways, and within these tubes cylindrical carriers or pellets of gutta-percha covered with drugget, containing written messages, are propelled by pneumatic pressure. The distance is seldom more than one mile, although this could be exceeded if necessary. The system is applied in all the principal cities of Great Britain as well as in Paris, Vienna, and Berlin. In the latter city, the tubes are utilised also for a special express postal service of letters, which, though less speedy than the electric telegraph, is quicker than the ordinary post. On a larger scale, the same system was about 1860 applied in London to the conveyance of large packages from a central office to one of the railway stations. In this case the tube was of iron, in shape like a tunnel or horse-shoe, 4 feet high and 4 feet 6 inches wide, and within the tube, running upon rails, was a carrier or waggon, provided with a disc or shield, fitting with enough tightness to the tube to act as a piston. A pressure of 4 or 5 oz. per square inch on the piston was sufficient to propel the truck. The system worked successfully, but has not been maintained or extended as was expected; the want of concord and co-operation among the various local authorities, and difficulties connected with the laying of the tubes in the public streets, being the chief retarding causes. Atmospheric pressure was tried in the earlier days of railway working, as a substitute for steam in the propelling of trains, but was found to cost more and to be less effective.

Concentrated air pressure.

Air compressors. *See also page 842.*

Air stored or conveyed in pipes.

Loss in process.

The most important application of air for conveying power, is that by which force is first concentrated, and then conveyed to the power-receiving machine. By special machines known as air compressors, to which power is applied from a steam-engine or other motor, air is compressed to a density considerably greater than that of the atmosphere; it can then be stored in closed reservoirs or portable vessels, or conveyed long distances in pipes, and applied to motors or machines of various kinds very much in the same way as steam, for, like steam, it is by the expansion or the release of elastic force that the power is given out. Considerable loss of power is incurred in the compression of air and in its application; and it is obvious that there must be grave reasons to justify such a transmutation of already existing motive force: these will be presently referred to.

Compression force wasted in heat.

Improvements in apparatus.

Little loss during transmission.

Loss from friction and leakage.

Leakage not always apparent.

Loss in application of air pressure.

Expansive force of air.

See page 572.

In the compression of air, much of the force applied is absorbed in the production of heat, which not only cannot be ulilised, but increases the resistance; and, if not counteracted, renders an unprofitably slow speed necessary, involving a larger proportion of piston leakage than would accompany a greater speed. The attention given to the subject as the usefulness of compressed air became apparent, and the greater knowledge acquired of all the working parts, have led to improvements which have greatly lessened the heat and leakage, and the proportion of available force obtained from a given expenditure of power has been greatly increased. Probably 70 per cent. is the maximum. But there are further losses in the transmission and application. The passage of the compressed air through pipes involves very little loss if the pipes are of sufficient diameter and properly jointed, and not too high a velocity is attempted; for though much air may be wasted by leakage through imperfect jointing, the friction of air in pipes is much less than that of water. For mere transmission of gross power in a direct line, the loss need not be more than 3 per cent. per mile (in some notable cases it has been less), and though the friction increases somewhat if numerous bends or regulating valves occur at the places of distribution, the loss when it occurs, arises principally from leakage, which is preventable by proper care. Leakage of air is not so apparent as is the escape of steam, water, or gas, and therefore more watchfulness is necessary to detect it; but by applying soap and water to suspected places, the leakage will be evident from the bubbles. A further and more serious loss has to be incurred when the compressed air reaches the machine in which it is to be applied; for, like steam, compressed air cannot within the compass of an ordinary machine be allowed space to expand to the atmospheric rarity which alone would enable it to give back all its accumulated force; but, after having bestowed its high pressure on the piston of the machine it escapes, and so wastes the remainder of its force. The air, when it has expanded in doing work, is so cold at the place of exhaust that it may be utilised for refrigerating, and its value in this respect, a by-product so to speak, may go far in certain cases to justify its use. The effective force of the air may be increased by heating it before it is applied to work, a small fire or even a lamp adding to the efficiency. In this case the full effect of the heat is obtained without the great loss which attends the application of heat through the medium of a steam-engine, *See* HOT-AIR ENGINES, *page* 608.

and such heating reduces the risk of excessive cold or freezing at the exhaust.

Further loss in application.

Aggregate loss.

Just as high-pressure steam has been found profitable because of the margin for expansion which it affords, so high-pressure air—if the difficulties in providing it be overcome—would allow economy by expansive working. But not only is it impossible to give to the machine all the power which was originally needed to compress the air, but the mechanism of the machine can only utilise, according to its kind and construction, from 60 per cent. to 80 per cent. of the force it receives. Assuming that ordinary care be used in the arrangement and use of the apparatus, the final expression of force or work done in the machines usually worked by air pressure is found, owing to the losses which occur in compression, transmission, and application, above described, only to equal, in the case of machines receiving upwards of 5 H.P., from 30 per cent. to 45 per cent. of the original power which was expended in compressing the air, and in smaller machines only from 20 to 30 per cent. The higher effect is obtained where the air is, as already stated, heated before using, and the cost of this heating must be taken into account.

Loss varies with mode of using.

Instances.

See ROCK-DRILLS, *page* 816.

The actual loss in working in any particular case depends partly on the purpose to which the compressed air is supplied. For instance, applied as in the ejectors before referred to, directly on the surface of a liquid to be lifted, or even if used for giving power to a slowly-moving pumping-engine, arrangements are possible for regulating the supply and expansion of the air which would not be feasible in a small, quickly-working rock-drill.

Convenience gained outweighs loss.

See CRANK-ENGINES *page* 798.

Economy of fuel in compressing engine.

In this respect the conditions and the comparison to be made would much resemble those which apply when steam is used for such dissimilar purposes. It must be borne in mind, however, that loss is always incurred in the distribution and application of power, and it has to be seen in each case whether the conveniences obtained outweigh the loss. For instance, small steam-engines worked intermittently are extremely useful and remunerative, even though they consume 10 lbs. or even 15 lbs. of coal per effective horse-power per hour, as against the 3 lbs. per hour which a large, well-managed, and constantly-working engine will consume. And if such an economical steam-engine be applied to the compression of air, which is then distributed in various directions to numerous small machines, even the great loss above described will express only a consumption of 12 lbs. for each effective horse-power. This will still leave an enormous gain in favour of the compressed air as compared with the cost of hand-labour, or even with steam-power conveyed and distributed considerable distances by shafting and belting. Electric transmission is in such cases the competing method.

See pages 508 & 513.
ELECTRICITY.

Power companies.
See also page 493.

Public companies have been established for the transmission and sale of compressed air as power, but the results obtained in Paris, Birmingham, and elsewhere do not encourage any wide extension of the system. In large cities there are numerous small industries where motors of from 1 to 10 H.P. are required, and where it is inconvenient and expensive to have steam-engines, and where even gas-engines have some disadvantages. Power transmitted by compressed air may be extremely convenient in such cases if it can be sold at prices profitable alike to the producer and consumer, but this would seldom occur except where, as in large cities, numerous consumers repay the great cost of installation. The alternative of transmission by electricity would in the vast majority of cases prove more advantageous. For small local motors and for continuous rotary machines, the elastic or expansive force of compressed air gives it an advantage over pressure water, but for intermittent and direct-acting operations such as hoists, cranes, and presses, water will generally be found best, although of course, if the air system has been established for the more appropriate services, it can be used for the latter also. The lower pressure of the air, generally not exceeding one-tenth of the usual water pressure, renders large cylinders necessary. On the other hand, the velocity of the elastic compressed air is greater than that of water, so that distributing pipes need not be so large as would be required for water of similar low pressure.

Air and water power compared.

Air transmission in Paris.

In Paris the system authorised in 1881 was, on a small scale, for giving motion to pneumatic clocks, which, as they took power from a central motor, had a synchronic action. In 1886 an extension of this system was authorised for transmitting power by compressed air for industrial uses of all kinds, the municipality claiming a share of the profits after a certain percentage was paid in dividends. The air is compressed to 85 lbs. per square inch, is stored in reservoirs of about 1000 cubic feet capacity, and is conducted in numerous cast-iron mains 12 inches diameter to the various districts, where it is distributed in small lead pipes to users. A large number of small industries take less than 1 H.P. each, and from this up to 100 H.P. for tramways and other purposes, the total force available being 3000 H.P.

85 lb. pressure.

Air compressed by water-power.

Cheap and useful for work in mines.

Examples in tunnels.

See pages 63 *&* 173.

Water-power is often situated near mines or places where compressed air is needed; and such power, developed at its source by a water-wheel or turbine, may be cheaply conveyed for many miles in pipes, and in many such cases where the power is abundant, the loss in transmutation which has been referred to is of little or no consequence. Notable instances of such transmission are afforded by the works of the Mount Cenis, St. Gothard, and Hoosac (Massachusetts) tunnels, where power has been conveyed from 2 to 5 miles by compressed air.

Air chiefly used in mines and tunnels.

See page 817.

Where air is preferable to steam.

Air ventilates and cools.

Purifies mines after blasting.

Air compressors instead of fans.

Stimulates workmen.

Depth of mine increases pressure.

Air substituted for steam in engines.

Such transmission of power finds its chief and most legitimate application in mining and tunnelling operations; in mining, for underground hauling engines, pumps, and coal-getting machines; in tunnelling, for rock-drills and locomotives. The work of a rock-drill is performed by a rapid succession of blows, for which a highly elastic force like steam or compressed air is well suited. Steam is generally used where the drills work in an open quarry or cutting to which a boiler can be brought sufficiently near, and in a tunnel also, if within 20 feet of the open face; for in such situations the exhaust steam need cause no inconvenience. But steam is almost unendurable in mines and tunnels; while air, besides conveying power, has the great advantage of ventilating and cooling the place where it is used. This would alone justify its use in mines, even if circumstances did not there forbid other methods. In tunnelling, where holes are drilled for inserting the blasting charge, the atmosphere is so foul after each explosion of gunpowder or dynamite that the workmen cannot enter sometimes for one or two hours. Where, however, the rock-drills are worked by compressed air, the atmosphere can be purified and cooled in a few minutes. In badly-ventilated mines, the air compressors are often kept at work for ventilating purposes only; the air so supplied having more local effect than that from ordinary ventilating fans. The air in deep or imperfectly ventilated mines is often hot and oppressive, and the miners cannot work to advantage. In such circumstances a supply of cool and dry air from the compressors will greatly increase their energy and capacity. In cases where air, compressed on the surface, is taken down into a deep mine, the weight of the column of compressed air (which is heavier than the outer air), and the expansive force added to the air by the higher temperature of the mine, not only compensates for the loss by friction, but renders the pressure at the place of discharge greater than that at the compressor. Where compressed air has been introduced into a mine, it has even been applied to winding or pumping engines previously worked by steam; the boiler being utilised as an air-container or reservoir. But where the cooling and ventilating just referred to are of no advantage, then the laying of electric conductors would generally be found easier and cheaper than the laying of air pipes.

Air for portable riveting machines. *See page* 764.

Compressed air is sometimes used for working portable riveting machines, to which the power may be conveyed considerable distances in pipes and flexible tubes. Compressed air is also used for working the brakes of railway trains, the power of the locomotive being utilised for compressing the air, which is then transmitted along the train in tubes to successive carriages, under each of which is fixed a container or store vessel for supplying as needed a cylinder with moving piston connected with the brake. The vacuum brake is an inversion of this plan, a pump on the engine exhausting the air in the brake cylinders, the pistons then being moved by the pressure of the atmosphere.

Railway brakes. *See page* 723.

Vacuum brake.

Compressed air in subaqueous work. *See* DIVING-BELLS, *page* 841.

Compressed air is used in subaqueous operations for supplying air to a diver in helmet and dress, or to a rock-drill which the diver works; for the diving bell; for the sinking of pier cylinders; for supplying submerged caissons; and for raising sunken vessels; the air pump or air compressor in these cases being indispensable. Compressed air has the advantage over either steam or water, that it is portable and can be conveyed in a detatched vessel long distances from the source of power, but the trouble and expense involved in doing this forbids such a use of compressed air except in rare cases. Thus compressed air has been used successfully for propelling tram-cars, the air being stored in a reservoir on the car and heated by a small stove before entering the cylinder of the motor. For this purpose it is rarely so advantageous as electricity, but it compares better for locomotives in mines, and for submerged torpedo missiles. It is obvious that high-pressure water is useless in cases of this sort, for, having no self-contained elasticity or force, its power is at an end directly it begins to work, if communication with the source be cut off. One of the difficulties in working engines with compressed air stored in a detached container, arises from the continuous dilation which goes on as the air expands or diminishes; special arrangements being necessary to maintain in the machine a constant power like that which is afforded by the continually replenished supply of steam from a boiler. The difficulty is generally met by interposing what is called a diminishing or reducing valve between the air reser-

Air stored in portable vessels.

As in tram-cars and torpedoes. *See* TRAM-CARS, *page* 316.

Air compared with pressure water. *See page* 494.

Difficulties.

How overcome.

voir and the cylinder, so as to bring the air to a uniform pressure before it is applied, or by variable cut-off valves.

Prices of air compressors.

With and without steam-engine.

Air compressors, for working by belt or gearing, and therefore without steam cylinder, cost from £30 to £300, and, if fitted with steam cylinders, about one-third more; the boilers necessary for machines of these sizes ranging from 5 to 25 horse-power. An ordinary portable engine will give power to a detached compressor by a belt from the fly-wheel; while, if the compressor be complete with steam cylinder, the power may be obtained by a steam-pipe from the engine boiler. Air compressors of this kind are suitable for working one or numerous rock-drills, and for pumping-engines of small size; but for permanent pumping-engines, or for supplying air caissons of considerable volume, or for any work on a large scale, a powerful compressor, complete with steam cylinder and boilers, would cost from £1000 to £2000.

See PORTABLE ENGINES, *page* 593.

Pressure, how measured.

The measure usually adopted for stating the air pressure is that of the atmosphere; compression to two atmospheres (about 30 lbs. per inch) or three atmospheres denoting the density. But the effective or working pressure is one atmosphere less than the gross force so stated, as there must of course be deducted the ordinary pressure of the outer air which is opposed to an advancing piston (unless a vacuum be artificially created), and, if working under water, a still greater resisting pressure. In blowing-engines for blast-furnaces, the effective pressure is from 3 lbs. to 5 lbs. per inch; the blast for a Bessemer steel-converter is about 30 lbs.; for rock-drills and coal-getting machines, 30 to 50 lbs.; for air-brakes, 50 to 70 lbs.; and for pneumatic telegraph or postal tubes, 10 to 12 lbs. Where compressed air has to be stored in a detached or portable vessel, as, for instance, for use in an underground locomotive, or torpedo, much higher pressures are attained; from 500 to 2000 lbs. per inch being usual limits for these purposes. Air compressors and accessories of a special kind are then needed, which are not adapted for supplying advantageously air of such density for long distances.

Pressure suited for various purposes.

High pressure.

Subaqueous work.

For subaqueous work, for supplying divers, either in the helmet or in the bell, the air pressure is not regulated as in the rock-drill by the force which it is necessary to give to a machine-tool, but has to be exactly proportioned to the depth, or head, or pressure of water to be overcome. In tidal waters the pressure may have to be varied from hour to hour.

See also pages 173 & 841.

Electricity.
See also page 254.
From steam or water power.
Loss in transmutation.

In allotting to *Electricity* its proper place among the various other systems described in this chapter, the advantages it affords for Transmission are to a considerable extent separate from those where Distribution of power is the object in view. Starting from the original motor by which some natural source of power is developed, such as fuel, by means of a steam-engine or gas-engine, or the gravity force of water by a turbine or wheel, the transmutation into electricity must involve some loss. For the purposes of the mechanical engineer it may be said that of the net energy given out by any one of such original motors to the electro-generator, 70 to 90 per cent. may be recovered from the electro-motor at the place to which it has been transmitted, if the losses by leakage and the resistance of the conductor are left out of question. That is to say, if the electro-generator and the electro-motor which gives out the force were placed only 20 yards apart, 70 per cent. may be recovered from small motors of 5 horse-power, and—the loss becoming less with larger machines—90 per cent. may be reckoned on with motors of 100 horse-power and upwards working at full load.

Leakage.
See pages 271 & 323.
Loss due to resistance.
See page 264.
Low voltage for short distances.
Usual minimum voltage.

The losses by leakage may be almost entirely prevented even with high voltages by the careful use of known means of insulation, and may be disregarded, although the cost of such insulation may form an important part of the total outlay. The losses due to the resistance of the conductor, which are those which really limit electric transmission, depend first on the specific conductivity of the material employed, secondly on the sufficiency of its sectional area or size for transmitting current of a given volume and pressure, and thirdly on the distance traversed. The transmitting capacity of a conductor with a given loss and of given diameter or area increases as the square of increase in the current pressure or voltage, and from these data the weight and cost of copper conductors may be calculated, as well as the limits of distance to which the electric current may be transmitted with advantage. Within a small area, as in or about a factory, where the distance never exceeds 400 ft., an electric pressure as low as 50 volts would suffice, as the weight and cost of copper to transmit even 100 horse-power would be of small account. If greater voltage is adopted in such a case, it need only be for such secondary reasons as the suitability of any particular voltage for lighting in lamps of a given standard, or to accord with customary fittings. In practice a less voltage than 100 is seldom adopted. Up to half a mile, transmission is still economically possible by a low-tension current, say, of from 200 to 500 volts, but as this distance is exceeded the importance of high voltage rapidly increases. As an example—to transmit 45 horse-power to the far end of a line 5 miles long, at a pressure of 1000 volts, and with a loss of only 10 per cent., a copper conductor of 0·122 square inch sectional area would be required, weighing for the double line 11 tons, which, with copper at £70 per ton, would cost £770. If the voltage were only 500, the volume of current would have to be doubled, and allowing the same percentage of loss, the sectional area of the conductor would have to be increased fourfold to 0·488 square inch, weighing 44 tons and costing £3080. But if, instead of a lower voltage, a high one of 2000 volts be used, the current might be halved, and the conductor be one-fourth the sectional area of the first example, or 2¾ tons, costing £192. Where the original power is abundant and cheap a greater loss than 10 per cent. may be afforded, but the cost of the generating plant is then greater, namely, in proportion to the gross power produced.

Advantage of high voltage.

Many of the schemes for electric transmission are for much longer distances than 5 miles, there being numerous examples available of distances between 5 and 20 miles, and the importance of high voltage increases accordingly. Thus, to transmit 5000 horse-power 10 miles with a loss of only 30 per cent. by resistance, with a pressure of only 2000 volts, the conductor must have a sectional area of 2·5 square inches, weighing 450 tons, for the 10 miles, and costing for copper alone £32,000. This would probably be prohibitive. But with a pressure of 10,000 volts, only 0·1 square inch of sectional area would be required; the conductor would weigh 18 tons for the 10 miles, and cost only £1280. If, however, it be attempted to transmit power 50 miles by the same pressure of 10,000 volts, and with a loss of only 30 per cent., the conductor would weigh about 9 tons per mile. This at £70 a ton would involve a cost for copper alone of £637 per mile, a prohibitive expenditure in the majority of cases. If, however, 20,000 volts were feasible and permitted, the weight and cost of copper would only be one-fourth of the above. The lower weights given above for high voltages, while theoretically correct, would need addition to allow for leakage and deterioration. It must be noted, moreover, in regard to all the above examples, that the total cost depends not only on the weight of copper, as determined by the voltage and the distance, but also on the system of insulation adopted. Long-distance transmission is economically feasible only where naked conductors on overhead poles are

Example of 10 miles transmission.

10,000 volts saving in copper.

Example of 50 miles.

Overhead conductors.
See page 267.

permitted. Insulation is then only necessary at the supports, where leakage can be prevented at moderate cost by the use of specially constructed insulators. But where, as in cities or on unfenced land, it is required that conductor cables insulated along their whole length shall be used, such insulation would cost more than the copper for any but very low tension currents, for while the weight of copper per mile decreases as the voltage is increased, the difficulty and cost of insulation become greater.

Costly insulation.

Water-power utilised.

Projects for utilising at a distance the force of water are fascinating, but the cost of the necessary works, such as dams, reservoirs, conduits, or other local adaptations, and the restrictions regarding the right of way, are generally very considerable, and may entirely outweigh the expected gain. The supply of cheap power is only one of many conditions that are necessary to the establishment of factories, and will not alone ensure success. Moreover, if the supply of power is liable to reduction in dry seasons, the cost of supplementary steam-power for such periods may go far to negative the apparent advantage. A favourable example of continuous power is afforded by Niagara, where also there is within a radius of 25 miles a great demand for the power, and similarly by other of the great waterfalls in different countries. Examples of another kind are seen in countries like Switzerland and Norway, where coal has to be imported. In both these cases electrical power is transmissible with advantage up to 20 miles, and even up to 50 miles if high voltage and overhead conductors are allowed, and if the demand is so considerable as to repay the great cost involved. On the other hand, in countries like Great Britain, where coal is abundant at moderate cost, and where the use of high voltage conductors for long distances is restricted, it would be cheaper to carry the coal by railway to the place where the power was required, or possibly still cheaper for distances up to 50 miles—if way-leave for the pipes were obtainable—to generate gas at the collieries and to transmit it as potential fuel force as already described.

Cheap power.
See pages 470–11.

As at Niagara.

In Norway and Switzerland.

Gaseous fuel.
See page 482.

Use of waste gases.

The waste gases from blast furnaces, coke ovens, and destructor furnaces are often unproductive, because there is no contiguous use for them, but by means of electric generators they might be utilised for machinery or electric lighting a mile distant.

It will be seen from the above considerations that transmission by electricity is feasible, and that the comparison with other systems is mainly a matter of cost and economy. A further development will depend on future inventions or improvements in the generation of high voltage currents, in the cheaper insulation of such currents, and in the safeguarding of the conductors. The objections to high voltage will disappear only when, by experience, the freedom from accident in conductors so charged is established, and it becomes evident that there is no more danger in the neighbourhood of a highly charged conductor than in contiguity to the high-pressure boiler of a locomotive or steamship, either of which, if imperfectly controlled, has a much greater capacity of harm. In this regard it is to be noted that as the causes of danger have become more generally known, the necessary precautions have been enforced by municipal and other regulations, and since 1895, although transmission by electricity has increased, the number of accidents has decreased.

Supposed danger from electricity.

Decrease of accidents.

It is not the purpose here to describe the method or particular kind of apparatus necessary for generating and transmitting electrical energy. It may be said, however, that it is neither easy nor convenient to construct dynamos for generating a direct current of more than 3000 volts, although, in effect, this higher voltage has been obtained by arranging several armatures in series. As the difficulties of insulation in or about the generating station rapidly increase with the voltage, most of the long transmissions have up to the year 1897 been effected by obtaining first a current of moderate voltage and then increasing the pressure for the main conductors by "step-up" transformers at the generating station, and reconverting the current by "step-down" transformers at the place of arrival into one of moderate pressure which can be conveniently distributed or applied. It is thus that at Niagara the water turbines generate 2400 volts; the current in the conductors is at 10,000 volts; and at the city of Buffalo, 26 miles distant, the current is delivered to the tramway and electric lighting companies at 500 to 600 volts for use with or without further reduction. If electric energy already available is to be utilised for transmitting power, the system and voltage must be made known to those who are to advise as to its application, and also whether the transmission is only to be in the gross to one point or is for distribution also.

Limits of high voltage.

Transformers. *See page 265.*

While it has been shown that distance and the exigencies of insulation are the dominating conditions that limit transmission by electricity, the Distribution of power depends on other circumstances. The adaptation of electricity for this purpose was for some time impeded by the uncertainty and cost of maintaining numerous

Distribution by electricity.

electric motors for giving out the power conveyed to them from a central generator. By improvements in these respects power can be distributed effectually in or about a factory or mine not only with less loss in the operation, but with less wear and tear than by steam or shafting or compressed air or wire ropes. As analogous, it may be said that an electric conductor has the same advantage over shafting, belting, and toothed wheels as the conductor wire of an electric bell has over the tension wires and cranks in the now obsolete domestic bell-ringing apparatus.

As preferable to shafting. *See page* 513.

In a factory, for instance, current from one large generator may be distributed to numerous smaller electric motors, one of which may be placed in each workshop, whence the power may be further distributed by shafting and belts. Experience has shown also that it is feasible and frequently economical to effect this local or retail distribution by electricity. Thus there may be a motor at each loom, or lathe, or planing machine, not only with less loss of power than shafting involves, but with no more wear and tear. The successful examples of this method had become numerous by the year 1897, and were increasing. The current may be taken with equal facility to machines using one-fourth of one horse-power, to a saw-mill requiring 50 horse-power, or to a 100-ton travelling crane, and with the additional convenience that this distribution may include transmission from a central engine 100 yards or 1000 yards distant. At the first application of electricity to travelling cranes, where there are numerous and subsidiary movements, as for propelling, travelling and traversing as well as lifting, it was not deemed expedient to apply an electric motor to each, and the power was diverted and applied by wheels, clutches, or other mechanical means. But owing to the success of the electric method, and the freedom from wear and tear of the motors, it has since proved advantageous to apply a separate motor to each of these movements.

A dynamo-motor to each machine.

Electric cranes. *See page* 807.

Electricity affords facilities for transmitting power to isolated machines. For purposes like these it was often found necessary to establish a small steam-engine at each of such places. Taking, then, into account the loss by leakage and condensation in the pipes from a distant boiler, a consumption of 100 lbs. of steam per effective H.P. is not unusual. Now, by a small electric conductor wire the power can be conveniently taken from the central generator, and if, after ordinary working hours, it is desired to operate one machine, a small generator, or storage batteries provided at the central station for such

Transmission to isolated machines. *See page* 736.

See page 571.

occasions, may supply the amount of power desired much more cheaply than if it had to be transmitted by steam, or shafting, or other means. Not only, however, are machines distributed over a wide area, but they may have to be moved from place to place, as in shipbuilding yards. The facility with which conductor wires may be taken to portable machines is then of great value.

See page 748.

The distribution of power to moving carriages on railways and tramways is one of the most useful applications of electricity, and one likely to extend. The methods of accomplishing this are described elsewhere. For distributing power in mines, and for hauling, pumping, or winding; or for conveying power by submerged conductors, electricity affords facilities obtainable by no other means, and its use is rapidly extending. Where a continuous current is to be applied, the designer of the dynamo-motor must be informed of the amperage and voltage available, but in the case of alternating currents to be applied by a 3-phase machine it is necessary also to know the periodicity or number of alternations per second.

See LOCOMOTIVES, *page* 315. TRAMWAYS, *page* 320.

Electricity in mines.

See also page 501. **Compressed air.**

In comparing transmission by Electricity with that by Water, although the cost of apparatus in the former may appear high and the net results obtainable less in some cases than with such simple and slowly moving mechanism as are obtainable from a hydraulic ram, the consumption of electric current may be more easily made to accord with the useful work done than is possible with hydraulic machines. In the latter, the quantity of water consumed is in most cases as great with a light load as with a heavy load. Electric distribution affords facilities for measuring the power generated and transmitted, as well as that applied to each machine, with the losses at each stage of the operation, an investigation not easy with any other system.

Hydraulic power. *See page* 486.

Electric power easily measured.

The transmission of power by *Connecting Rods* is, for general purposes, limited to very short distances, for in most kinds of machinery a rotary motion is required; and the crank by which this is obtained from the reciprocating movement of a connecting rod requires, for its effective working, an alternate push and pull, for which long connecting rods without intermediate supports are quite unsuited. Even in a steam-engine the connecting rod which transmits power a few feet from the piston-rod to the crank, is made of form and strength far in excess of what the tension requires, to resist the transverse strains incurred in pushing the crank; and the rod, if its length were

Connecting rods.

How limited.

Unsuitable for long push.

Rotary motion by tension only.

increased, would soon become unwieldy and impracticable. Rotary motion can, of course, by the use of a fly-wheel, be obtained by pulling only, as for instance, in a lathe, where a chain connects the treadle to the crank; but in any but simple cases this is neither equable nor effective. By means of a ratchet and pawl, a slow rotary motion may be obtained from the tension of a connecting rod, but except for such purposes as a ratchet drilling-brace, or for some minor movement in a larger machine, this system of transmission is seldom suitable.

Long rods, how used.

For pumping.

Long connecting rods have found their chief application in pumping from mines, and, in recent times for the working of railway points. Pumping machinery is often erected with a view to its temporary use only; and, whether temporary or permanent, advantage is frequently taken of a steam-engine or water-wheel situated at a considerable distance from the pump-gear. In England, connecting rods are found to transmit the necessary force without inordinate friction for distances up to 3000 feet. Not only on the surface, but in the underground workings of a mine, power is thus transmitted, the rods working horizontally or at any inclined angle; the total distance of rod-transmission from the original motor on the surface being sometimes as much as one mile. The power is generally applied by means of a bell-crank or quadrant at the top of the mine-shaft, the crank being pulled, and the vertical pump-rod lifted at each stroke of the connecting rod; the weight of the vertical rods being sufficient (they sometimes weigh more than 50 tons) to ensure the downward movement of the pump-bucket or plunger, and therefore the return stroke of the connecting rod. The distance to which it may be profitable or expedient thus to transmit power depends on many considerations: the cost of the rods with their supports; the intervening obstacles, such as the inequality of the ground to be traversed; the loss of power by friction; the right-of-way for the rods; and the proportion which these circumstances bear to the comparative expense and the convenience of motive power placed nearer to the point where it is to operate. Such considerations have, in England, limited the transmission-distance above ground to about 3000 feet, as just stated, but under more favourable circumstances much greater distances may be traversed. Thus, in Sweden, there are instances of power derived from a waterfall or rapid being conveyed by connecting rods even as far as four miles, for use at mines; the transmission rods having often to traverse irregular and hilly country. Such a

By bell-cranks. *See page* 616.

Return movement effected by weights.

Distance, how limited.

In England, 3000 feet maximum.

Power transmitted 4 miles by rods.

gratuitous source of power justifies a much greater loss by friction than could be afforded if the power had to be obtained by the expenditure of fuel. The cheapness of timber for the rods, and a free right-of-way, also tend to render such long transmission feasible. The rods are strapped with iron, and are supported on rollers or rocking-posts placed at intervals of about 50 feet. Iron rods are sometimes used where the work is light; but for transmitting considerable power, stability against transverse and compressive strains is better obtained by the use of wood; and iron rods are seldom employed except for short distances.

Loss by friction justified.

Rods, how made and placed.

Where chain is used for pulling over a wheel, or wire rope for pulling a crank, the return motion is obtained either by a second chain or rope, or by means of a balance-weight or spring. The two chains, which, from the steering wheel in the fore part of a ship, pull on each side of the tiller at the stern, are an example of the former method: and the wire rope and balance-weights by which railway signals are worked are examples of the latter. As chains can only act in tension, there is always a risk, where the return motion depends on a balance-weight, that derangement in the return motion may occur without giving any immediate indication to the operator; for the actuating lever may be duly pulled back by the local weight attached to it, even though the chain wheel at the further end may not have responded, or the chain may have buckled or kinked. The use of stiff rods instead of a flexible conductor greatly reduces these risks, because, although the effective service may still be performed by tension, the resistance which a rod will—if properly guided—offer to compression, goes far to ensure the return movement. On modern ships and steamers the steering wheels are sometimes as much as 300 feet from the rudder, and, although the force is conveyed entirely by tension, yet rods or stiff wire rope have been generally substituted for chain except at the immediate connection with the wheel and tiller.

Transmission by chain.

Examples.

Risks of derangement.

Connecting rods preferable.

Example of tiller-rods.

Till about 1870, Railway signals within stations were almost invariably worked by wires or wire cable, and switches also, if at more than a few yards distance from the operating lever. Such a method of transmission has not always proved adequate for the safe working of a railway, under the conditions of busy traffic usual in England, and the occurrence of numerous accidents rendered improved systems necessary. Wrought-iron tubes, which combine much strength and stiffness with moderate weight, have been employed as a substitute for

Railway signals.

Railway rods, how made.
See TUBES, *page* 654.

wires or cables for operating points, and occasionally also for signals. The tubes have generally a diameter of from 1 inch to 1½ inch, and are carried on guide-rollers placed at intervals of from 6 feet to 8 feet, and as these cause considerable friction, the force required to pull over the lever increases rapidly with the length of transmission. Since 1890, tubes have in their turn been superseded on some railways by solid bars of wrought iron or steel, of square or channel section. The stroke or travel of the rod seldom exceeds 8 inches, and where the transmission distance is great, variations in the length of the rods by expansion and contraction in a varying temperature have an appreciable effect. The Board of Trade regulations forbid a greater distance for the working of facing-points than 450 feet; but, for trailing-points and for signals, power may be transmitted 1000 feet. This distance may be considered the limit of transmission by connecting rods for these purposes, and for longer transmissions—such as for distant signals which are sometimes placed as far as 4500 feet from the operator—wire rope is used.

Affected by varying temperature.

Board of Trade regulations. *See page 678.*

Interlocking system. *See page 677.*

Improvements.

The constantly increasing traffic, the high speeds, and the general adoption of the electric block and interlocking systems on English railways, have greatly enhanced the importance of adopting the best transmission methods; and the constant attention of railway engineers has brought the various kinds of apparatus to great perfection. But further improvement is still sought with regard to the connecting rods, in the methods adopted for meeting alternations in temperature; the various systems in use not having always proved effective. It is generally sought, by dividing the total length into sections, to make an expansion in one section compensate exactly for an opposite expansion in another; but even this precaution sometimes proves insufficient where the variations in temperature are irregular—as for instance, where part of the rods are situated in a tunnel or deep cutting, and the remainder on an exposed embankment.

Transmission by shafting.

Shafting was up to 1895 almost invariably employed for distributing power to numerous machines, but for conveying gross power it is only expedient to use it for short distances; an engineer's factory or a cotton mill being an example of the former, and the fly-wheel shaft of a land engine, or the screw-shaft of a marine engine, examples of the latter. The engine or other motor is placed as near the point of

Short distance for gross power.

Toothed wheels *versus* belting.

See BELTING, *page* 516.

distribution as possible, as the cost of the machinery and the friction in working increase rapidly with the distance of transmission. Where the power has to be conveyed in numerous directions or to many different workshops, the transmissions are effected by toothed wheels or by belting, the main transmissions being sometimes taken by ropes running in grooved pulleys. But the use of toothed wheels greatly limits the speed of the shafts, and it is on the principle that quickly-running shafts are the most economical for transmitting a given power, that belting or ropes are preferred more often than formerly.

The laying out of shafting.

Distance apart of bearings.

Couplings and pulleys.

Should be near bearings.

Motor placed midway in line of shafting.

Long line shafting causes loss of power.

See page 508.

The primary consideration in laying out shafting is to have the supports at proper distances apart, so that while, on the one hand, there may be no unnecessary bearings (as each adds to first cost and to the friction of working, as well as being an obstruction), there may, on the other hand, be no risk of flexure with shafts of moderate diameter. Some distance between 8 and 12 feet is generally adopted where there is free scope for choice; the lighter the shafting the nearer the bearing required. In cases where it is impossible or inconvenient to have bearings so near—as for instance where a shaft spans an open yard or public street—it may become necessary to truss the shaft to enable it to resist flexure. Another important consideration is the arrangement of bearings, couplings, and power-transmitting pulleys in relation to each other, for it is desirable to have couplings as near the bearings as possible, and it is even more important that the power-transmitting pulleys should also be arranged near bearings, for they impose great strains upon the shaft. For any but moderate distances it is expedient to place the steam-engine or motive pulley in the middle of the line, and to take the shafts right and left from it, so as to diminish the length of each. In this way shafting may be taken as far as 1000 feet in either direction from an engine, but although, by careful arrangement and workmanship, the friction can be minimised, such long lines of shafting are only expedient when the necessities of distribution along the line are such as to justify a considerable expenditure of power in conveying it. In workshops where there are only few machines, it would generally be cheaper and more convenient to supply each with an electric motor, and to bring the power by an electric wire from a central dynamo-generator. Such a plan also allows of variations in speed to each machine, according to the severity of the work it has to do.

Shafting, how made.

The details of shafting, and its various accessories, have been brought to great perfection. The shafts themselves, for diameters not exceeding 4 or 5 inches, are turned from solid rolled bars of wrought iron or steel, but it is sought in some cases to avoid the expense of turning, by using bars so planished by cold-rolling as to have a bright smooth surface. Large diameter shafts are forged under the steam-hammer and then turned in the lathe, though sometimes only the journals or bearings are turned. The exact form which turning alone gives, is, however, very useful in allowing free scope for bearings or pulleys at any point. Every wheel, pulley, or coupling should be balanced, and the importance of these precautions increases with the velocity, for, as any irregularity in form, or want of balance in the shafts or pulleys, gives, at each revolution, a blow to the fixed parts, the vibration from these causes will, at high speed, shake loose or destroy the entire apparatus; while rough or seamed journals cut or wear away the bearings. For high-velocity shafts conveying considerable power, or where the distance between the bearings is necessarily great, hollow tubes have in some cases been used, so that while retaining a diameter sufficiently large for the bearings and to resist torsion or flexure, the weight may not be excessive. The large propeller-shafts of steam-ships are sometimes made hollow by boring out the middle, because the original steel ingot from which the shaft is made is not considered so sound in the middle from a possible excess of carbon there. There are great differences of opinion as to the methods of coupling shafts —flanges, sockets, bolts and keys being applied in various ways. The coupling should be so designed that the shaft is at least as strong there as anywhere else, and it may be said generally that standard sizes should be adopted, so that couplings of the same nominal size may be interchangeable and fit accurately on shafts of given diameter; and the shafts should be so regulated in size as to allow the free passage over them of any wheel or pulley which it may be desired to attach. Couplings with conical bushes grasp shafting firmly, even if the diameters do not exactly accord. Owing to the great facilities afforded by "split" drums or pulleys in placing them at any place on the shaft, projecting couplings are no impediment, and therefore the strongest form of coupling—a flange forged solid on the shaft—may be used.

Large shafts.

All revolving parts should be turned and balanced.

Especially for high speeds.

Hollow shafting.

Couplings.

Standard sizes.

Bearings or supports for shafting are needed in a very great variety of form and size; wall-brackets, column-brackets, hangers and pillow-blocks of varying dimensions being necessary for the different situa-

Various kinds of supports for shafts.

See FACTORIES, *page* 477.

tions that present themselves. And when belts are substituted for geared wheels, the exigencies of position or angle frequently require swivelled or adjustable bearings of various kinds. The frequent bearings for shafting of course require beams, columns, or walls for support, and it is best to have all these under cover. Sometimes these necessities may be modified by laying the shafting in a trench in the ground, a plan frequently adopted, for instance, in a saw-mill, where overhead belts would hinder the free moving of timber, and where, because of the high speed of the shafting, the solid support of the ground is advantageous, as affording a steadier bearing than the elevated or side supports of columns or brackets. Where the machines are so placed that the belts from below form no obstruction, the plan may be best, but it has certain inconveniences.

Bearings should be under cover.

Shafting laid below ground.

Reasons for and against.

The shafting of a factory, with its numerous bearings, couplings, wheels, and pulleys, should be considered, not only in relation to its ultimate purpose of transmitting power, but as itself a machine. On the proper proportioning of the various parts, on the balancing of quickly-revolving wheels and pulleys, on the accuracy of the bearings and on the methods of lubrication, depend, not only the cost of repairs, but the daily cost of keeping the whole in motion. Many factory owners are quite ignorant of the power absorbed in doing this, and the measurement of the force expended in turning the shafting while all the machines are idle would often be very useful. The power thus absorbed frequently exceeds 50 per cent. and in some cases even 70 per cent. of the gross force of the motor; and where the work of the machines is intermittent, and much shafting is kept running without doing useful work, the proportion of unremunerative expenditure will be greatly increased. It is impossible to fix long lines of shafting absolutely true on rigid bearings, and pivoted bearings which adapt themselves to an irregular line save much friction. Numerous transmissions by toothed wheels add greatly to the friction; bevelled tooth wheels especially having this effect, owing to end pressure or thrust on the shafting. A large percentage of power may be saved by efficient automatic lubrication, the bearings being in effect constantly running in oil. In large factories, where the work to be done is constant and uniform, one central engine of considerable power generally proves the cheapest, as space, fuel, and attendance are economised; but where, as often occurs, one or few machines may, at times, alone be wanted, the plan is sometimes preferred of having numerous small engines and

Shafting considered as a machine.

Cost of working, how determined.

Great loss in transmission.

Pivoted bearings.

Lubrication.

One central engine and much shafting.

Numerous engines and less shafting.

less transmission shafting, or to distribute the power by electric conductors from one central dynamo. The choice between these methods depends not only on the local circumstances which make the course to be traversed convenient to one more than to the other, but on the nature of the operation to be effected—revolving or only reciprocating, constant or intermittent, slow or quick in its movement, and whether requiring much or little force.

Choice of method, how determined.

Power by shafting sold to users.

Power is in some cases distributed by shafting to different users, who pay rent for it ; this custom prevailing in many manufacturing towns where craftsmen of various kinds require from ½ to 10 horse-power for driving their machines. Sometimes the power alone is hired, but generally it is provided by the landlord of the tenements—often a factory owner, who has spare rooms to let—the tenants, who thus hire power as well as room, having, of course, to conform to the prescribed hours of working, or to pay at a higher rate for extra hours if the steam-engine be kept running for them alone.

Power leased and included in rent.

While, however, the above remarks apply where transmission by shafting is preferred or adopted, the whole subject has been revolutionised by the facilities afforded by electricity as already described.

See ELECTRICITY, *page* 508.

Transmission by belting.

Belting may be said to find its principal use in the distribution rather than in the transmission of power, and even those engineers who prefer toothed wheels to belting for conveying gross power from a steam-engine or other motor, generally agree that belts are better suited for distributing or retailing power to numerous machines.

Belts preferred for distribution.

Belts unsuited for slow speeds.

Belt-transmission does not compare favourably with gearing for slow speeds, and when it is so used it is because of the supposed cheapness or simplicity allowed in the construction of the apparatus, or because of special difficulties in the way of gearing. Belting is not suited for transmitting exact speeds, for there is a liability to slip, which varies according to tension, temperature, tightness of the belt, smoothness of the pulleys, and other circumstances. Thus, it is unfitted for a clock or indicator, for the screw-cutting apparatus of a lathe, or for giving motion to the governor of a steam-engine ; although it is frequently used for the latter purpose where great exactitude is not required. Pitch-chains used as belts meet, to some extent, this difficulty. The slip, or "creeping," of a belt varies according to its grip, and to the strains put upon it, and it is evident that where there are several successive transmissions, the aggregate slip may alter greatly the proportionate revolutions of the power-receiving machine

Nor for exact speeds.

Pitch-chains. *See page* 521.

Slipping of belts.

and the motor. The grip of a belt can be increased by covering the pulley with buff-leather, paper, or other material which increases the friction; but such methods are seldom adopted except for special purposes and small machines. For wire-rope transmission the bottom of the pulley grooves are covered, this as much to prevent damage from the rubbing of two metallic substances as for giving grip to the rope. The separate wires of the rope are sometimes laid together in a special manner so as to give a smooth surface when used for running round pulleys. Chalk or resin is often applied to leather belting to increase the grip on the pulleys, but these substances harden the leather, and are undesirable. The liability of a belt to slip, while incompatible with exactitude of speed, is, however, the very circumstance which renders this kind of transmission preferable to gearing for certain operations. Thus, for instance, in driving a circular-saw, if the timber be pushed forward too rapidly, or a hard knot be encountered by the saw, some part of the apparatus must yield or break; and the belt, slipping on the pulley, affords the necessary relief. So, also, in starting machinery—if toothed wheels, running at a considerable speed, be thrown into gear with a heavy machine, the inertia of the latter cannot immediately be overcome, and there is a liability to fracture. A belt transferred in the usual way from a loose to a fast pulley acts in such a case the part of a friction clutch, and slips sufficiently, during the first few revolutions, to give time to the power-receiving machine to attain its proper speed.

Grip, how increased.

Slipping, sometimes an advantage.

Instances.

Fast and loose pulleys.

Belting is obviously more convenient than gearing for temporary transmission, or where the distance from the motor to the machine or the relative level of their positions is liable to variation, as a belt can be readily applied and adjusted without the preparation and exactitude which geared wheels and their support involve. Thus, from a portable engine to a thrashing-machine, stone-crusher, or mortar-mill, the gross power of a steam-engine is almost always taken by belting.

Belting convenient for temporary use.

Examples.

Belting has generally been considered by English engineers as unsuitable for transmitting the gross power of large engines, but the example set in the United States, of using belts or ropes instead of toothed wheels for such purposes, has been followed by many engineers in Great Britain.

Transmission of gross power by belts.

As in America.

The whole subject of belt-transmission has been thoroughly investigated, and elaborate tables, based on numerous experiments, are available for reference. Opinions differ, not so much in regard to

Theory of belt transmission.

Power depends on tension.

See HORSE-POWER, *page* 568.

Strength of belts.

Working strain on leather belts.

Allowance for friction.

Centrifugal force.

Large driving-belts in America.

High velocity.

the theory of calculation—for there is a general concurrence as to the principles involved—as in regard to the deductions drawn and in the working rules recommended. The power which a belt can transmit is measured by the strain or tension imposed on it (depending on its sectional area and the quality of the leather) multiplied by the velocity, the foot-pounds of force per minute thus transmitted being equal to a certain horse-power. The ultimate breaking strain of leather belts varies, according to their kind, from 3000 lbs. to 5000 lbs. per square inch of sectional area, but there are wide differences of quality. The effective strength is limited by that of the lacing or riveting by which it is joined, and by the leather becoming worn and weakened by use. It is considered expedient, therefore, to have a considerable margin of strength, and a working strain of from 250 lbs. to 300 lbs. per square inch of sectional area is usually adopted; from 50 lbs. to 55 lbs. tension on a belt 1 inch wide $\frac{3}{16}$ thick being an example. From the gross tension given to the belt has to be deducted, to obtain the net result, a certain proportion which serves only to overcome friction on the pulleys, and though there are variations in friction arising from different causes, one-fourth is generally considered a fair allowance. As an approximate rule, a belt-surface velocity of 60 feet square per minute may be taken as required for each horse-power transmitted, but as belts vary in thickness such a rule may need qualification, belts of double or treble thickness affording increased strength in proportion to their greater sectional area. When belting is run at an excessive speed the centrifugal force has the effect of relaxing its grip on the pulleys. In the United States, where—as has been said—belting is used for transmitting much greater power than is usual in England, main driving-belts are made of all widths up to 36 inches, and 4000 to 5000 lineal feet per minute is considered a proper speed; this speed being obtained more by the use of large diameter pulleys than of high-speed shafting.

Distance apart of pulleys.

Extreme tightness to be avoided.

It is generally considered that belting works most effectually when the pulleys are at such a distance apart that the weight of the upper belt affords considerable adhesion on the pulley; and that the belts should be of such width and have such a contact with the metal as to transmit the desired power when thus running slack; so that the adhesion may not have to be obtained by extreme tightness of the belt, which might strain the shafting too much. But the evil effect of short tight belts generally arises from the lap jointing of the belts, which causes alternate tightness and slackness as they pass over the pulley. Butt joints with metallic fastenings overcome this difficulty. Belts always incline to the greatest diameter of a pulley: hence the rounding of the rim prevents the belts slipping off. If, however, the distance between the pulleys is too great, the belts—slacker as their length increases—work unsteadily, especially at high speeds, and become cumbersome and dangerous. Between main driving pulleys the distance seldom exceeds 30 feet, and between minor distributing pulleys 20 feet, while in the majority of cases shorter distances are usual. For longer spans, in exceptional cases, intermediate pulleys or rollers both for guiding and tightening the belts become necessary. Moreover the belting can then be enclosed in wood casing, and even allowed to skid on the inner surface of the boarding if the latter be lubricated with black lead and tallow.

Slackness.

Power can be transmitted by belting from one shaft to another not parallel to it by twisting the belt, and the belt has then a greater grip-surface on the pulley; but unless carefully effected, excessive side strains may be imposed on the shafting or machines. Difficulties of this sort are overcome by having intermediate pulleys for altering the direction of the belting; and power, where so guided, can be transmitted round corners, although the loss by friction is by such a method much increased. Where the direction or line of transmission is subject to variation, swivelled pulleys allow the necessary latitude to the belting.

Twisted belts.

Intermediate pulleys.

Swivelled pulleys.

Although leather is the most usual material for flat belting, other materials are also employed; canvas, vulcanised india-rubber, or both combined, and gutta-percha, being the most common substitutes. What is known as Gandy's cotton belting has also been largely used even for transmissions exceeding 100 H.P. These substitutes for leather are considered preferable sometimes when the belting is to be exposed to damp or steam, but they are also used where no such conditions prevail, because they may be at a particular time and place cheaper than leather. Canvas belting is, however, unsuitable if there is much slip, as the friction heats the oil and causes a considerable reduction in speed. The quality of leather differs very much in different countries, and the superiority generally conceded to English leather lies rather in the mode of manufacture than in the original quality of the hides. Bark-tanning produces the best leather for general purposes, and the English climate favours the growth of the best oak bark. A variety of other materials—hemlock bark,

Materials for belts other than leather.

Canvas belts.

Quality of leather.

Bark tanning.

Substitutes for bark.

gambia, valonea (oak-apples), myrabolams—are employed for tanning where oak bark is scarce, but the average quality of leather so produced is less. In England, moreover, more discrimination is exercised in dividing the hides into various parts for different treatment; so that even though the same average of quality may be produced by foreign tanning, the better parts of the hide receive in England more attention, and afford for those who are willing to pay, the best leather.

High-quality leather.

But, although leather of the best quality for general purposes may be produced by oak-bark tanning according to the English system, it is a much-disputed point whether leather so manufactured is the best for all purposes. For instance, hemlock-tanned leather, though not of such good appearance, is extremely hard and durable for boot soles; and similarly, in the opinion of some engineers, the oak-tanning process, carried out in the manner usual in England, for high-priced leather, is not the best suited for belting, in that it reduces the original tenacity of the hide. A lasso rope of dried hide is, for instance, stronger than a similar rope of leather, and the tedious manipulating process by which, in the preparation of such lasso ropes, the flexibility of the hide is retained, has been imitated by a machine process for making what is called "fulled raw-hide leather" for belting. The qualities of leather so made have not, however, been sufficiently tested to justify its general adoption in preference to bark-tanned leather, and except where it is important to obtain a maximum tensile strength, the latter would probably be preferable.

Hemlock-tanned leather.

Dried hide lasso rope.

Round ropes as belts.

Materials for round ropes.

Cotton rope.

Round ropes are frequently used instead of belts, partly because of the direct advantages they are supposed to afford, and partly because where good leather is scarce, they facilitate the substitution of other materials. Belting ropes are made of leather, raw or half-tanned hide, hemp, manilla, or cotton, but cotton is preferred by the majority of users. Leather of inferior quality, which would fray or break if used in the form of a flat belt, may be twisted into a very strong rope. One effective method of doing this is to lay a flat belt upon another of double the width, unite them by one row of stitches down the centre, and then to twist the belt, thus doubled, into a rope. Raw or half-tanned hide has, when twisted into a rope, a tenacity 1½ times that of flat leather belts of the same sectional area. Ropes are often more convenient than flat belts, and in some factories have entirely superseded them. A flat belt is often inconvenient, its edges are

Hide rope.

obtrusive, it needs wide pulleys, and the transmission, if it be not in a direct line, requires elaborate arrangements for directing it. But even where there are no such special circumstances, ropes are preferred by some engineers. Single ropes are used for distributing power to small machines, but the system is characterised by the use of numerous ropes running on the same pulley in a series of grooves side by side. Thus—to take one instance—in a jute factory in India the entire force of an engine of 1000 horse-power is taken by 18 cotton ropes from the fly-wheel, which is made of a drum form, 6 feet 7 inches wide, to receive the necessary grooves. The fly-wheel is 28 feet in diameter, making 43 revolutions per minute, the ropes being each 2 inches diameter, 11 of the ropes taking the power in one direction, and 7 ropes in the other. When ropes run in opposite directions friction in the main bearings is considerably reduced. The subsequent transmissions for distributing the power are made also in a similar way, smaller and fewer ropes being used as the power becomes less. But to work this system effectively the pulleys and grooves should be accurately turned, so as to ensure that the working diameter at each groove is exactly similar. And as, to carry out this, the ropes should be of the same diameter and length, no new rope should be inserted till by stretching, or otherwise, it is the same as the ropes that have been strained in working. The grooves should have straight sides at an angle of about 40°, so that the rope does not touch the bottom of the groove. The pulley should not be less than 30 times the diameter of the rope, and a diameter of 50 times is better.

Belts *versus* ropes.

Numerous ropes in grooved pulleys.

Strains balanced.

Precautions necessary.

There is said to be less risk of stoppage with cotton or hempen ropes than with the usual flat-leather belting, as the ropes, which are worked at strains very much below their ultimate strength, give early warning of deterioration or coming fracture; and even the breaking of one out of numerous ropes does not involve the stoppage of the machinery, a new rope being substituted after working hours. There is the disadvantage in rope-transmission of this kind that the arrangement usual with belting, of fast-and-loose pulleys for starting and stopping the machinery cannot be adopted, and other means have to be used instead.

Cotton and hempen ropes.

Starting and stopping.

Another method of power-transmission which may be included in this category is that by pitch-chains, which, though not suitable for the usual purposes to which belts are applied, can, under certain circumstances, work effectively at low speeds. Such chains have no slip, for each link of the chain fits upon a tooth of the sprocket-wheel,

Transmission by pitch-chains.

and the driving and receiving wheels maintain a similar or exactly proportionate speed according to the number of teeth on each. Indeed, transmission by pitch-chains may be considered as an elongated system of spur-wheels, with the marked difference, however, that with the pitch-chain, both wheels revolve the same way. Pitch-chains are sometimes used, not because they are without slip, but because in the open air they are more durable than leather or rope belts, or because they can be used for longer distances; in this latter respect performing somewhat the same function as a wire-rope transmitter, presently to be described. Pitch-chains are often used in England in brick-fields or other situations where the work is rough, and they are used also as conveyors for carrying coal, ore, bricks and other materials. The pitch chains of bicyles afford another example.

Have no slip.

Transmission of power by belting, including in this term the rope substitutes above described, is, as has been already stated, limited to short spaces; and for longer distances rope transmission of a different kind becomes necessary.

Wire-rope transmission.

Teledynamic cables.

Quick-running cotton ropes.

As in travelling cranes.

See CRANES, *page* 807.

Wire rope is used for the transmission of power where the opportunities for belting end; but for distances up to 100 feet, or even 150 feet, shafting is generally to be preferred. The teledynamic cables—as the endless, transmitting ropes are called—are of comparatively recent introduction (few were in operation before 1860) and have been only rendered possible by the modern invention of wire ropes; but on a much smaller scale, and with hemp or cotton ropes, somewhat the same system was at an earlier date employed for short distances. Transmission by hemp or cotton ropes is in this way found convenient where the power-receiving machine is at a varying distance from the motor. Thus, in a travelling crane, a rope running from end to end of the staging or gantry may be passed round the wheel on a travelling bridge, and without any alteration in length may draw the bridge backwards and forwards at will. In cranes of this sort it is sometimes undesirable or inconvenient to have workmen on the crane itself; and the entire working of the winch, and the various travelling motions, may be performed from below by the rope more conveniently than by shafting. Where the travelling crane is protected from the weather, cotton or hempen ropes will suffice, and a rope $\frac{5}{8}$ in. diameter, running at a high speed, will propel the travelling bridge, the traversing winch upon it, and lift weights up to 10 tons easily and quickly. This method has, however, been largely superseded by the use of electric motors on travelling cranes, a method which allows of varying speeds.

See ELECTRICITY, *pages* 508 & 807.

Another example is that of a railway traverser for conveying locomotives or carriages across a railway station, or a still longer distance across many lines of rails in a station-yard. A hempen rope ½ inch diameter, laid in an open trough a few inches below the ground and passing at one end round a drum on a motor shaft, and, in its course, round a wheel on the traverser, will draw or propel heavy loads smoothly and quickly. Until about the year 1848 the trains on the Blackwall railway were drawn by long hempen ropes continuously running. In modern times the same principle has been carried out for propelling tramcars with wire rope.

Used on traversers.
See page 676.

And tramcars.
See page 317.

The introduction of wire rope, and its adoption for the standing rigging of ships, for hauling wagons up inclines, and for winding from mine shafts, sufficiently proved its strength and endurance; and the application of it for power-transmission is the logical outcome of this experience. Iron and steel are strongest in the form of wire, which, in proportion to its diameter or sectional area, has a tensile strength many times as great as the bar from which it has been drawn. The breaking strain of steel wire is at the rate of from 60 to 120 tons per square inch of section. Several wires being twisted into a strand, the rope is generally formed by laying several strands round a hemp core; ropes or cables so made having the aggregate strength of all the wires, less a diminution calculated at from 5 to 10 per cent. for loss by twisting. The exact strength and flexibility of a wire rope depend upon the quality and temper of the wire, and the manner in which it is twisted and laid; and as several varieties of wire rope are made, the manufacturer should be informed of the purpose for which the rope is required, the diameter and kind of pulleys, and the tension at which it is to be worked. An iron rope ½ inch diameter will bear from 3 to 4 tons tension, and an iron rope 1 inch diameter 15 tons before breaking; a 1-inch steel rope, if hard, as for ships' rigging, will bear 30 tons, and if flexible, for moving round pulleys, about 20 tons; one-sixth being considered a fair working strain.

Strength of wire rope.

Wire rope, how made.

Strength and flexibility vary.

The amount of force or energy which a rope will transmit in a given time depends upon its tension multiplied by its velocity, the foot-pound units so ascertained corresponding to a certain horse-power. It is the application of this principle which forms the basis of the teledynamic cable system. Ropes of small diameter are

Force depends on tension and speed.

See HORSE-POWER, *page* 568.

utilised by running them quickly, the desired speed being obtained by making the transmitting pulleys on the motor shafts of large diameter.

Usual speeds.

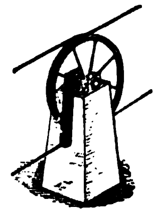
In practice the pulleys are of all sizes to 15 feet, and cables of from ½ inch to ¾ inch diameter, with speeds of from 3000 to 5000 feet per minute (about 30 to 50 miles per hour) transmit any required force up to 400 horse-power. As the rope is subjected to a strain from flexure as it passes round pulleys, and as it has, moreover, to sustain the weight of its own catenary when suspended, the tension from these causes must be deducted before the effective strains can be arrived at.

Non-effective tension.

The amount of non-effective tension depends on the diameter of the rope and that of the pulley, and on the length of the spans.

Mode of working.

The power is taken by the rope passing round a grooved pulley of large diameter on the motor shaft, and, like a belt, transmitting the force to another pulley at a distance. The pulley to which the force is thus transmitted has a second groove upon it from which another rope conveys the power onwards to a third shaft, and so on by a succession of stages for a mile or more. In the most notable examples of this system, the total distance varies from a ¼ mile to 1 mile; but it has been calculated, on the basis of experience already acquired, that 120 horse-power could be transmitted 12 miles with a loss only of one-fourth in the process.



93.

Difficulties.

Difficulties connected with right-of-way, and the protecting and keeping in repair so many moving parts extended so far, render the opportunities for such long transmission rare, and 2 miles would be generally the practicable limit.

Length of spans.

The separate spans vary from 300 to 500 feet, and though it is not easy to determine the maximum space which would be practicable, it would certainly not be less than 600 feet.

Deflection of ropes.

But, while long spans like these are feasible, there is necessarily a considerable deflection or sag, and if the rope be not high enough to clear the ground, idle pulleys or rollers must be placed as intermediate supports.

Power taken up hill and across rivers.

Power is thus conveyed long distances, not only horizontally, but up and down hill (though the weight of the cable limits the ascent), across rivers and ravines, and even through water. Cases arise where the power of a steam-engine may with advantage be thus transmitted to a distance, but the system finds its chief application in utilising the natural force of water by transmitting it to a convenient place. Power from a waterfall or rapid is sometimes conducted down stream by conduits or pipes laid parallel to the river; but by wire ropes the power can, if necessary, be taken up stream or across it. Wheels or turbines having been first employed to develop the power, electricity, wire-rope, compressed-air and high-pressure water are all utilised for transmission, according to the purpose for which the power is to be applied and other local circumstances.

Water-power transmitted by wire rope.

The whole question of power-transmission has attracted most attention in Switzerland, where waterfalls and rapid rivers abound; but where, in most cases, the site and immediate vicinity of the fall are not suitable for factories. At Oberusel, near Frankfort, the motive power of a waterfall 263 feet high is utilised; and about 100 horse-power is transmitted by wire ropes more than 3000 feet horizontally and 145 feet downwards, in spans of about 400 feet. At Schaffhausen the current of the river Rhine is utilised by turbines of more than 700 horse-power, and the power is transmitted by wire ropes to numerous factories. At Fribourg, situated on the Saone (a branch of the Air); at Bellegarde, where the *Perte du Rhône* represents probably a force of 2000 horse-power; and at Zurich, where the lake discharges by the river Limath, the natural forces of the water-flow have been utilised and transmitted by wire ropes; the system having in these cases a particular value owing to the dearness of fuel for steam-engines.

Transmission in Switzerland.

See page 493.

See page 479.

Wire-rope transmission has proved useful also for collecting power from different sources to one common centre, an inversion of the distributing principle described above. Thus at Kehlhof, in the Toess Valley, a cotton-spinning factory derives power from an adjoining waterfall; but this being insufficient, the force developed by a turbine from another fall nearly a mile lower down on the same river, is brought back to the factory by wire-rope to supplement the local power.

Collection of power.

In Switzerland power-transmission by the wire-rope system was undertaken by private persons or companies; and in some cases, especially when allied with a water-supply scheme—by the municipal authorities. The power has been leased or sold to factory owners and craftsmen of various sorts; but the various associations which have been established for this purpose have not reaped the anticipated profit, not on account of engineering errors either in the water-motors or rope-transmissions, but from economical mistakes in the extent of the works, the capital outlay, and the expected earnings. The mere creation of powerful motors and the distribution of power at low prices will not at once transform an isolated locality into an industrial centre, for many other conditions are necessary to success.

Commercial conditions not always favourable.

Sale of power.

The price paid for power from the wire-rope stations ranges from 120 fr. to 150 fr. per horse-power per annum; and, in some cases where local transmission-shafting for bringing the power to the outside of the factory of the hirer is supplied, an additional charge of about 30 fr. per horse-power per annum is made. The turbines and wire rope run twelve working hours per day, and are stopped during the night, on Sundays, and on four holidays in the year, to afford opportunities for repair. If necessary for important alterations or repairs, stoppage to the extent of twenty working days per annum may be made without compensation to the hirers; but beyond this a rebate in the rent may be claimed by them.

Included in rent.

Wire rope superseded by electricity.

See page 504.

Transmission by wire rope as described in the preceding pages, found its best developments in the years 1860–90. Since 1890, however, the alternative of power-transmission by electricity has to a large extent superseded it.

The various means of transmitting power which were summarised on pages 480–81 having now been described, it may again be said, in conclusion, that no comparison between different methods can be established for general application, and that a choice between them in any particular case can only be made after consideration of all the circumstances enumerated on page 480, full information about which should be furnished to those concerned.

[*See also* FACTORIES: STEAM-ENGINES: MACHINE TOOLS.]

CHAPTER XX.

THE COMMERCE IN COAL, IRON, AND STEEL.

The uses of coal enumerated. *See also* MINING, *page* 357.

ENGINEERS are concerned in the uses of *Coal* in various ways, but mainly for the evaporation of water in steam-boilers; the smelting of ores; the melting, puddling, and other processes of iron-making; the making of steel; and the production of illuminating gas. For these very different purposes, each kind of coal has its particular value. The comparative powers of the different kinds consumed in generating steam are generally expressed by the number of pounds of water which are evaporated by the combustion of one pound of coal, and the power and value of coal in this respect mainly depend upon the amount of carbon and hydrogen it possesses. One pound of English coal will evaporate from 6 lbs. to 11 lbs. of water, and with limits so wide the proper choice of coal is evidently a subject of great importance.

See page 386.

See page 242.

Coal for generating steam.

See page 572.

Coal varies in evaporating power.

Coal used for melting ores and metals.

For the melting of ores and metals, the comparative values of different kinds of coal cannot be so easily defined as in either water evaporation or gas-making. Although the strength and other qualities of iron and steel which determine their value vary greatly, the chemical differences which produce these qualities are minute, and depend to a considerable extent on the qualities of the fuel with which the metals are brought into contact. Coal has usually to be coked before it can be used with advantage in a blast furnace or foundry cupola, and its suitability for this process, as well as its calorific or melting power, goes far to determine its value. All coal and coke

Coking of coal. *See pages* 386 & 535.

Freedom from sulphur.

contain sulphur, and for most metallurgic processes the degree of impurity in this respect is of great importance.

Coal for gas-making.

See CANNEL, *page* 242.

For the production of illuminating gas, the calorific power of coal is not of primary consequence; the volatile matter contained by the coal, and which is given out in a profitable form as gas, being the measure of value. English coal yields from 7,000 to 14,000 feet of gas per ton, and has a value for gas-making accordingly, although of course the purity and illuminating power, and the amount of the residual coke, are also to be taken into account.

Classification of coal difficult.

Bituminous coal.

It is not possible to classify exactly the different kinds of coal, nor indeed can it be positively determined what minerals may be included in the generic appellation coal. The various kinds found in the United Kingdom may, however, be broadly divided into *Bituminous*, *Anthracite*, and *Cannel*, though it would be more correct to call many of the kinds semi-bituminous or semi-anthracite.

See COKE, *page* 535.

Bituminous coal, which is the most abundant in Great Britain, and which may for the present purpose be said to include all coal not in the other two classes, is found in almost all the coal districts, and although it varies very much, it is used for all the purposes named above. It is from a particular kind of bituminous coal, only found in certain districts, that most of the coke used in iron-smelting is made.

Anthracite coal.

American anthracite.

Is hard and requires strong draught.

But has little smoke.

Welsh coal for use in steam-ships.

See pages 533 & 572.

Mixed coal.

Anthracite coal is smokeless, and is useful for special purposes, but such anthracite coal as is found in the United States is not by English users considered so suitable as English coal for any of the purposes enumerated on page 527. But in America it is used as fuel for smelting iron, for which purposes its hardness renders it suitable without coking. When used for other purposes where there in no blast, special arrangements for creating a strong draught are necessary, but when once well kindled it will, if the draught be regulated, give economical results. The smokelessness of anthracite coal and its freedom from dust are advantages which go far to compensate for drawbacks in other respects. Much of the steam coal of South Wales may be classed as semi-anthracite, and is particularly valuable for use in steam-boilers, as in proportion to its bulk or weight it will evaporate more water than any other kind. It has its highest value in steam-ships, where economy of stowage space is important. As, however, it is slower of combustion than the more bituminous coal, and requires a strong draught, in some cases it is found expedient to mix it with the latter to assist combustion. Owing to the small quantity of sulphur in semi-anthracite coal, it is useful as fuel for making certain kinds of iron and steel, its hardness being no obstacle to its use where combustion is stimulated by the blast of a furnace. The Welsh anthracite is also used on river steamers in England because of its smoklessness, and is for the same reason used for boilers, bakers' ovens, and other purposes in large towns where there are municipal regulations against smoke. Its freedom from sulphur causes it to be used as the best fuel in malt-kilns. On the other hand, as it evolves, when carbonised, but little volatile matter, it has hardly any value compared with other English coal for making illuminating gas.

Semi-anthracite free from sulphur.

And from smoke.

Different uses.

Not suitable for gas-making.

Cannel coal, well known by its hard smooth texture, and best obtained in the district of Wigan and Newcastle, and the Boghead coal of similar kind found in some parts of Scotland, have their highest value for gas-making, as they will give out gas about 20 per cent. more in quantity than that from bituminous coal, and of higher illuminated power.

Cannel coal.

Where found.

Is best for gas-making.

See page 235.

Patent fuel is made from the small slack and dust which is screened from the larger coal, compressed, sometimes with clay, but generally with some bituminous compound, by hydraulic power into rectangular blocks. This coal generally sells for about one shilling per ton more than the ordinary coal, and it has the advantage of stowing compactly, and of being easily handled. In England its use is confined almost entirely to steam-ships, and, if compared with ordinary coal for such purposes, it is generally considered slightly inferior to coal from the same mine, the convenience in stowage being its chief recommendation. Engineers, however, are not agreed on this subject. Patent fuel is largely used in the locomotives of French and Belgian railways; and on a few of the American railways patent fuel made from the dust of anthracite coal is used.

Patent fuel.

How made.

Compact for stowage.

Used in steam-ships.

And as fuel for locomotives.

Coal is exported in large quantities from Great Britain to Continental countries for almost all the purposes—smelting, gas-making, steam-generating—to which such fuel is applied, and no export duty nor legislative restriction of any kind hinders the foreign purchaser who finds he can buy in Great Britain to advantage; and many of the foreign countries which impose high duties on British manufactures, admit coal almost entirely free of duty as an essential aid to their own industries. It is not the mere abundance of coal in Great Britain which renders it so cheap for use abroad, but its contiguity to the sea-

Export of coal.

Free from duty.

Cheap sea-carriage. *See page* 363.
Renders coal cheap abroad.
English coal in India.

board and the unrivalled facilities for shipment and cheap sea-carriage which are available. Thus, it is cheaper to purchase English coal and carry it across the ocean to South America for use there in steamers and for gas-making, than to dig it from the Brazilian mines, and carry it one-hundredth part of the distance along bad roads. So also, large quantities of English coal have been taken to India, for use there on railways and steam-ships; for although coal abounds in India, and may in some districts even be bought at low prices with moderate rates for carriage, yet it is often dearer than imported coal when measured by quality as well as by price.

Coal-shipping ports in England.
In Wales.
In Scotland.

The principal coal-shipping ports in Great Britain are Newcastle-on-Tyne, which is so near to the famous Northumberland collieries that much of the coal is put directly on board the ships from the colliery wagons, with but trifling cost of railway transit; Sunderland, at the mouth of the Wear, and Hartlepool, which are equally well situated for the Durham coal-fields and the famous Durham coke; the Bristol Channel ports of Cardiff, Swansea, Llanelly, and Newport, where the steam coal of South Wales is shipped, and where the pits are situated within three to twenty miles of the sea; Liverpool, where Lancashire and Yorkshire coal is sent for export; Birkenhead (included in the port of Liverpool), to which the railways from the Cheshire and North Wales collieries converge; Hull, Grimsby, and Goole, the principal ports from which the steam coal known as South Yorkshire and the Barnsley thick-seam is despatched; Glasgow, Greenock, Leith, and Granton, the chief ports for the Glasgow hard splint coal; and Boness, on the Forth, where the mines of cannel coal are actually by and under the sea.

Total quantity exported in 1888.
Proportion from each district.

In 1878 the total export from Great Britain was 15¾ million tons. In 1888 the total production of coal in the United Kingdom was 162 millions of tons, and of this, 23½ million tons were exported, of which approximately the following proportions were shipped from the above districts:—

4¾ million tons from the Tyne.
10½ „ „ Bristol Channel ports.
2 „ „ Sunderland and Hartlepool.
1¾ „ „ Hull and other Yorkshire ports.
¾ „ „ Liverpool and adjoining ports.
3 „ „ Scotland.
Patent fuel from all parts 540,000 tons.
Coke „ „ 660,000 „

Export in 1894–5.

In the year 1894 the total export reached 31¾ millions of tons, of which 16¾ millions were shipped from Bristol Channel ports. In 1895 the total production of British collieries was 190 millions of tons, of which 43 millions were exported.

Exclusive of bunker coal.

The above quantities are exclusive of the coal and patent fuel taken in the bunkers of foreign-going steamers for use during the voyage, and also of coal carried coastwise.

Facilities for shipment. *See* CRANES, *page* 805.

Coal broken in loading.

Precautions to avoid breakage.

Saving in expense.

At the principal coal-shipping ports the facilities for loading vessels are very complete, as by means of well-arranged docks, railways, inclined planes, hoists, cranes, and shoots, the ships are not only loaded expeditiously and cheaply, but with the minimum damage to the coal. Coal is necessarily broken during the process of shipment, but great ingenuity has been exercised to prevent it. Instead of allowing the coal to fall from the shoots a considerable distance to the hold, the shoots are in some cases adjusted to allow of a moderate fall at all levels of the tide or cargo; and in others the coal is lowered in boxes or wagons, which are emptied only when they reach the accumulating heap of coal in the hold. If all the elements of expense, including that of demurrage on vessels lying idle, be taken into account, it will be found that the cost of shipment is represented by pence per ton, where formerly shillings were expended.

Risk of ignition and explosion on shipboard.

Ventilation of coal in the hold.

Erroneous precautions.

Coal broken in shipment is not only rendered less valuable, but becomes specially liable to spontaneous combustion and gas explosion during the voyage. The large number of coal-laden vessels lost annually from this cause has had the effect of raising the rates of insurance, and even of disinclining some shipowners from coal cargoes altogether. Much stress has been laid upon the importance of ventilating the cargo, and to the neglect of this precaution most of the losses have been attributed. But by careful and exhaustive inquiry it has been ascertained that by ventilating the mass of the cargo, combustion is promoted, as the air so admitted makes the gases more inflammable. The precautions really necessary for the safety of coal cargoes are:

Proper precautions.

1. The avoiding of certain descriptions of coal, which are intrinsically dangerous for long voyages.

2. The prevention of breakage in the passage of the coal from the mine to the ship's hold.

Pyrites.

3. Care in avoiding the shipment while in a wet condition of coals containing a large quantity of pyrites (all coal contains more or less).

Ventilation of coal cargoes.

4. The ventilation of the surface of the coal in the hold so as to allow the escape of gas, while avoiding the admittance of atmospheric air to the mass of the coal.

Choice of coal depends on locality.

Cheapness sought by mixing coal.

See GAS-WORKS, *page* 242.

Choice for export.

The best is cheapest.

Freight and charges common to all.

Where the expense of carriage from the collieries to the place of consumption differs very much for different kinds of coal, it is not always advantageous to buy the better kinds; and at each place, according to its locality and the cost of carriage from the various collieries, must the choice be made. Economy is sought sometimes by mixing different kinds of coal together. Thus at gas-works, in the vicinity of which bituminous coal is obtained, the engineer will use cannel sparingly, and will probably arrive by experience at a combination of the two kinds which, as regards the outlay for coal and the quantity and quality of the gas, will give the most advantageous results. So also in steam-ships, if loading at Newcastle or South Wales, a mixture of different local kinds may be selected, or at a coaling station a mixture of Newcastle and Welsh coal may recommend itself as cheapest; the question being determined by the suitability of the furnaces for particular kinds, the importance of maintaining high speed, and other circumstances. But for use in a foreign country, far from any source of supply, it may be stated as an almost invariable rule that the best coal of its kind should be imported. The freight and charges may amount to two or three times the first price of the coal, and it is obviously advantageous under such circumstances to purchase only the best. Coal, which will evaporate 10 per cent. more water than another kind, or which will produce 10 per cent. more illuminating gas, will have found in England its level in price and be 10 per cent. dearer. If this 10 per cent. represents at the port of shipment 1*s.* per ton difference in price and the cost of freight is double the price of the coal, this superiority which has been purchased for 1*s.* is at the port of arrival equal to 3*s.* per ton.

Screening of coal.

Double screening.

Where expedient.

For the same reasons the coal should be shipped in the best order, and in addition to the usual screening at the colliery, which is considered necessary for home consumption, a small extra price is sometimes paid at Welsh ports (though very rarely on the Tyne) for a second screening at the place of shipment. But, though this extra screening may be of advantage to coal shipped as merchandise and to be discharged and stored for re-sale, the expense is of doubtful expediency for coal to be consumed on board, and especially if the coal be hard.

In selecting coal for use abroad, not only its quality for the ultimate purpose has to be considered, but its fitness for sea-carriage, the stowage-space it will occupy, and its suitability for storing. Some coal is softer or more friable than others; and the loading, the rolling of the ship, and the discharging at the port of arrival, break it up and reduce its value. And, as coals differ considerably in the stowage-space they occupy, a ship of certain capacity will take more of one kind than another, the differences between various kinds being—in proportion to their weight—as much as 20 per cent. Some of the Welsh coals occupy only 38 cubic feet to the ton, but shippers generally reckon that a space of from 42 to 45 cubic feet is occupied by each ton of coals, and it is not till a ton can be stowed into 40 cubic feet that the ship's space is most profitably occupied. Shipowners naturally prefer the heavier coals, which, when all the space is occupied, will have brought the vessel down to its proper water-line and afford the greatest freight remuneration. Gas coals are, as a rule, heavier than steam coals. Coal is liable to a loss of effective power by voyaging and by storage in hot climates; and as the deterioration varies with the kind of coal, it is important to take this also into account. For instance, the Welsh steam coal, which may be best for immediate use on board a steamer, will lose more of its calorific power by storage in a hot climate than will bituminous coal, and therefore the supplies sent to certain coaling stations are often selected from the more bituminous of the Welsh coals, which are not of the highest value at the port of shipment.

Suitability of coal to bear carriage and storing.

Friable coal.

Space occupied in stowage varies.

See page 362.

Deterioration by climate and storing.

Coal selected accordingly.

Where the place of consumption is far from the source of supply, it is expedient to keep a sufficient stock in advance as a safeguard against possible delays in the arrival of a fresh supply. This course is especially necessary where no other fuel can be obtained to supply a temporary want; therefore at important coaling stations and at foreign gas-works, coal is generally stored in large quantities; and at most foreign ports there are merchants who keep a stock of coal to sell to all comers.

Importance of sufficient stock.

As for steam-ships and gas-making.

As coal is constantly fluctuating in price, and occasionally is subject to great variations, the trade, for those who are obliged to buy in advance, is somewhat speculative; but apart from such fluctuations, and equally important to the consumer abroad, are the variations in the cost of sea-carriage. Some of the causes which determine freight have been already alluded to, and the purchaser of coal for export has to watch these closely. The naval authorities, steam-ship owners, foreign railway and gas companies, and others abroad who require

Fluctuations in price.

And in cost of freight.

See page 445.

British coal, make bargains for several months or sometimes even years in advance; and both in regard to the price at the port of shipment and the cost of freight, the purchaser, the coal proprietor, and the ship-owner alike have to estimate the probable prices during the period, and in the terms of their bargain discount the future accordingly. But there are constantly occurring opportunities for shipping coal profitably. As at those foreign ports to which British ships are sent coal is always a saleable commodity, it is a common practice among ship-owners, ship-brokers, or merchants, when there is a lack of more profitable cargo, to fill up the vacant space in the hold with coal, in the certainty that, whatever the current price of coal at the port of discharge may be, some profit or freight remuneration will remain beyond the cost of the coal in Great Britain, which will be better than having taken ballast. Small quantities of from 20 to 100 tons are often taken in this way; but in such cases friable coal, such as was referred to on page 532, should be specially avoided, as with other cargo placed above, it is specially likely to arrive at its destination broken and ground to pieces. Indeed the liability to damage in shipment, transit, and unloading is so great that part cargoes of coal always fetch a less price per ton at the port of arrival than entire cargoes of coal. Often, also, when there is a likelihood of profitable homeward cargoes, merchants, in the absence of any special demand for other commodities, will send out as a venture a ship laden with coal; and the agents in Great Britain of coal users abroad are generally empowered to charter such ships whenever the total price—cost, freight, and insurance—can be brought below a certain agreed sum.

Contracts in advance.

Speculative shipments.

Small quantities as ballast cargoes.

Part cargoes fetch only low prices.

In establishing a line of steam-ships or a gas-works, or in conducting any enterprise in a foreign country which involves great consumption of coal, the certainty of a supply at a cost which may be approximately estimated beforehand is a question of the first importance. When British coal is required, and the port of arrival is well frequented, the local conditions which may affect the freight or terms of chartering are sure to be known by those concerned; but if the port is a new one, or only suitable for certain kinds of vessels, full particulars concerning harbour accommodation, dues, facilities for discharge, and chance of return cargo, are necessary to allow of a vessel being chartered on favourable terms.

Cost of coal important in many undertakings.

Coal-ship charters.

Rates of freight, how determined.

Coals have been occasionally, in Newcastle and neigbouring ports, sold by the "keel" of 424 cwt., but are now sold there as elsewhere,

Measure of weight and value.

by the ton of 2240 lbs.; and the seller is by the custom of the trade supposed to give slightly in excess, so as to cover errors in weighing. In the United States the ton of 2000 lbs. is usually adopted. The coal is rarely weighed at the port of discharge (the tonnage and draught of the vessel giving a near indication of the weight), the buyer generally agreeing to take the bill-of-lading quantity as correct without weighing, subject sometimes to a deduction to cover mistakes. The amount to be deducted is a matter of bargain, 2 per cent. being a usual allowance. In other cases, captains will not sign bills-of-lading for precise quantities which they have not been able to verify, but will only sign for "quantity unknown, all in the ship to be delivered." Coal is sometimes taken improperly from the cargo during the voyage for use in cooking or for other purposes, and a store is even put by for the return voyage. It is therefore generally stipulated that the captain shall buy a certain quantity of the cargo at an agreed price, or that the ship shall carry a specified quantity for her own consumption stowed apart from the general cargo, and in the case of steamers, a special agreement is made concerning the bunker coal.

Weighing of coal.

Allowances for mistakes.

Coal for ship's use allowed for.

When coal is to be purchased in Great Britain for use in a foreign country, all the circumstances of the case should be communicated to those who have to choose the coal. If for generating steam, a description of the boiler; if for gas, the kind and size of retorts, methods of purification adopted, the quantity of gas required from a specified number of retorts in a given time, and the conditions in regard to illuminating power and purity which are imposed; if for smelting ore or melting metals, an analysis of the ore or metal should be furnished, with a description of the furnace and the blast; if for puddling, steel-making, or other metallurgical operations, the nature of the material to be treated, the kind of apparatus, the process, and the results desired should be given. Whatever the use to which the coal is to be applied, it is important to have a description, with prices, of any local fuel available, so that not only may the expediency of mixing the local and imported coal be considered, and the selection of the latter be modified to suit such a combination, but also that the total outlay for purchase, carriage, and insurance may be set against the cost of local fuel, and a comparative measure of value arrived at.

Circumstances on which choice of coal depends.

See page 242.

Comparison with other coal and local fuel.

Coke is used principally in the smelting of iron, for which purpose most English coal is unsuitable, because it swells and cakes together,

Coke.

Why and where used.

As superior to coal.

prevents the regular descent of the ore, and does not allow the free passage of the blast. These conditions apply particularly to the rich bituminous coals which, when coked, are the best for smelting; and the superiority of coke to coal justifies the expense of the intermediary process of making it.

Various kinds of coke.

Gas-coke inferior.

See GAS-WORKS, *pages* 242 *&* 250.

How made.

Unsuitable for melting-furnaces.

Uses for gas coke.

See page 850.

Value depends on that of other fuel.

Coke is of various kinds, and there are numerous methods of making it; but it may be broadly divided into two classes, i.e. coke made at gas-works, where it is the residuum of coal after the main object of extracting illuminating gas has been accomplished; and coke made directly for its own sake. In the first case the coal is generally selected for the quantity and quality of illuminating gas which can be obtained; the process of coking is also directed towards these results; and the coke is less in quantity and value than that produced from coal selected purposely for coke-making. For extracting gas, coal is placed in closed retorts, to which heat is applied outside; and the residual coke is light and quite unsuitable for the smelting of ironstone or the re-melting of iron in the foundry, for it is not strong enough to bear without crumbling either the burden in the furnace or the intense blast by which the fire is stimulated. Such coke is used as fuel for open smithy fires, for the heating of buildings, often also for domestic purposes, and is largely consumed in towns and places where smoke is prohibited. In London enormous quantities of coke are made at the various gas-works in and about the metropolis, and more than half of it is used in the manufacture of Portland cement. The value of gas coke is determined by that of other fuel in the locality, with which it has often a forced competition, and in districts where coal is cheap it has even happened that the coke has been disposed of only by giving part of it gratis to whoever would fetch it from the gas-works.

Qualities of coke for iron and steel making.

Sulphur in coke.

The exigencies of smelting, and the scientific precision with which all the operations in iron and steel making are conducted, have elucidated the qualities which are necessary; not only strength and combustibility being important qualities, but freedom from impurities, particularly sulphur, which has an ill effect upon the metal brought in contact with it. It is usual for certain purposes to improve coke by crushing it and—if the coke be of inferior quality in this respect—washing it with water, the latter process ridding it of much of the sulphur it possesses. In other cases the coal is washed before coking. In coal suited for the production of coke a combination of qualities is needed not often met with, and in the United Kingdom the best kind of coking coal is obtained in the Durham district, where much of the rich bituminous coal affords good coke, and in a certain limited part of the South Wales district, where a peculiar bituminous anthracite is found. Coke is made in other coal and iron districts, but though occasionally used for smelting where, because of long carriage, the better coke is expensive, its use is as far as possible confined to metallurgic processes other than melting and not requiring a strong blast.

Durham coke. *See also page* 386.

Welsh coke.

The various qualities of coke are mainly exhibited in difference of density, colour and combustibility. According to the kind of coal and manner of coking, the quantity, by weight, of coke produced ranges from 60 to 80 per cent. of the coal treated. As an average, it may be stated that coal when coked loses one-fourth in weight and gains one-fourth in bulk. These proportions do not apply to gas coke made from cannel, which is much lighter.

Differences of kind.

Weight and bulk.

From 1 to 1½ tons of coke are consumed in the production of 1 ton of pig-iron from ore, and in a foundry cupola from 150 lbs. to 350 lbs. of coke is necessary for re-melting 1 ton of pig-iron, the exact quantity being determined by the quality of the coke, that of the ore or iron, the nature of the blast, and the skill in the arrangement and management of the furnace or cupola.

Quantity of coke needed to smelt and melt iron. *See page* 386.

Coke was at one time largely used in the furnaces of locomotives, as it afforded a more concentrated heat than coal, and was much more easily managed. It has been found, however, that by suitable fire-boxes and by more continuous and careful stoking, coal, which is cheaper than coke, can be used with advantage, while the steam blast in the chimney destroys most of the black smoke which is caused by the use of coal. Most of the railways which established coking-ovens have abandoned them, and the quantity used in locomotives is very small as compared with coal.

Coke as fuel for locomotives.

Now superseded by coal.

Coke is almost always sold by weight; but as, owing to its extreme porosity, it will absorb much moisture, the quantity of water it may contain is an important consideration in determining its value when weighed. Coke is occasionally sold by measure of bulk, the chaldron of 36 bushels being the unit employed in England; from 13 to 14 cwt. per chaldron being approximately the weight of good coke, the density or weight going far to determine the value of the coke as fuel for melting. The price fluctuates not only with that of coal but also with the briskness of the iron and the steel trades; and in busy times prices are proportionately higher, and the profits of coke-burning greater.

Coke sold by weight.

Sold by bulk.

Price of Durham coke.

Export.
See page 530.

Considerable quantities of coke are exported to Spain, Russia, and other Continental ports for foundry use, and also for smelting ore; for though smelting is seldom carried on with profit, except in countries where coal is plentiful and coke can be produced near the collieries or furnaces, coke is occasionally imported for the smelting of local ore in countries where the protective duties hinder the competition of iron made elsewhere under more natural and more favourable conditions. The export of coke beyond Europe is very small, India and South America taking the most, for use in the melting of foundry-iron and for other purposes in engineering factories.

Quantity exported small.

Sea freight of coke.

Weight and measurement of coke.

The sea freight of coke is charged by the ton of 20 cwt., but the rates are higher than for coal, because of the greater space occupied. But there is no fixed proportion between the weight of coal and coke occupying the same space; for coal varies much, and coke much more. The "keel" of coke used sometimes, though now very rarely, as a measure of freight on the Tyne, is by custom accepted as equal to 11 tons, while the keel of coal equals 21½ tons.

Pig-iron.
See also page 382.

Varieties in kind.

Pig-iron, as the immediate product of the ore-smelting furnace, is iron in the first stage of manufacture, rolled or malleable iron being obtained by after processes. There are great differences in pig-iron, caused primarily by the quality of the ore, and then by the kind of fuel and the mode of smelting; and certain districts have, because of the ore and fuel there obtainable, and the methods of making, become associated with certain kinds of pig-iron. The principal difference in process is that between the cold-blast and the hot-blast iron. By the latter much less coal, even allowing for that consumed in heating the blast, is required to melt the iron, and the melting is much quicker. Except for special purposes, such as for "chilled" rolls, steam cylinders and other special castings where hardness and strength are required, or for the making of high-class mealleable iron of the Farnley or Lowmoor kind, the cold blast is seldom used, and probably not more than 2 per cent. of the blast furnaces in the United Kingdom are so worked. Cold-blast iron costs about double hot-blast iron, and has a strength, as measured on an ordinary test bar, from 20 to 30 per cent. greater. But although the hot blast is applied so skilfully as to have overcome prejudices which at first existed against it, and though high-quality pig-iron can be produced by it from suitable ore, the extreme power of the hot blast when applied to

Cold-blast and hot-blast iron.

Small proportion of cold blast.
See page 549.

See page 541.
Inferior iron produced by hot blast.

inferior ore undoubtedly produces iron mingled with impurities which the cold blast would have left behind in the form of dross and slag.

The best irons are made in South Shropshire, Staffordshire, Derbyshire, South Yorkshire, Lancashire, and Lanarkshire, while the greatest quantity is made in the Cleveland district. The name of the district is not, however, so sure a guide to quality as formerly, for the exhaustion of mines in some places, the opening out of new mines, the facilities for carriage from one iron-producing district to another, and the demand for low-priced castings and for cheaper malleable iron, have entirely altered the traditional customs of the iron trade. In South Staffordshire, which formerly was the principal centre, many of the mines have been so far worked out that the cost of getting the ore is too expensive, and inferior ores are brought from other counties to mix with the local sorts. In Scotland, also, although the reputation of particular kinds or brands has been generally maintained, the relative excellence of different brands varies from time to time. The constituent parts of the ore are liable to variation as mines are further explored or new mines become associated with existing brands; and as, moreover, the management of the blast furnaces is occasionally modified, such changes are accounted for. The greatest innovation in the Scotch districts is the import thither of the cheaper Cleveland iron, this commerce having attained enormous proportions. On the other hand, Scotch, hæmatite, and other high-quality irons are imported into the Cleveland district to mix with the local iron when high tests are demanded. Large quantities of Spanish ore are imported into England for steel-making.

Iron districts.

See also page 380.

Local qualities altered.

Mines exhausted.

Mixture of ores.

Iron varies though brand remains.

Cleveland iron mixed with Scotch.

See page 383.

The iron-making advantages in Cleveland are the abundance of the ore, the nature of the deposit which cheapens the cost of getting, and the close contiguity of coal and limestone. These advantages were developed by the skilful application of the hot blast; but the trade could never have attained its subsequent proportions had it not been also for the unequalled facilities for shipment; this combination being more favourable than that of any other iron-making district in the world. Cleveland iron is generally sold at a much lower price than that from other of the principal districts, and therefore commands a vast sale, notwithstanding its moderate quality; this lower price being remunerative to the makers, because it is all applicable to the expenses of manufacture, without deduction for inland carriage. In the future, however, the iron of Alabama and Tennessee, in the United

Local advantages of Cleveland.

Shipping facilities.

Iron sold at low prices.

See page 383.

States, where there are similar advantages, will rival the cheap English iron in neutral markets.

There are three principal uses for pig-iron; for re-melting in the Foundry, for making wrought or malleable iron by Puddling, and for converting into Steel. For use in the foundry, expensive cold-blast iron is sometimes mixed with other or inferior irons to improve their quality, and for particular purposes it may even be used alone.

Quality of Scotch iron.

The best of the Scotch irons are much stronger than the cheaper English irons, and are also distinguished by fineness of texture, the metal setting when cold into small crystals, which favour the

Produces fine castings.

casting in the foundry of thin and sharply-defined forms difficult of attainment with the iron from other districts. Thin rain-water gutters, fire-ranges and light ornamental castings are for these reasons made with advantage in Scotland; and Scotch pig-iron is sent to all

Castings made from mixed iron.

parts of the country for mixing with local kinds. Much skill has been exercised by the Scotch founders in making castings of the accustomed kind and form from the cheaper mixture of Cleveland with Scotch iron, but castings so made have not the quality which their appearance may indicate. Tenacity and toughness are the qualities

Quality often disregarded.

most needed in cast iron, but for a large proportion of iron castings neither superior strength nor fineness is deemed of great importance by purchasers, because the size and thickness of the castings may be so far in excess of what would be necessary to resist (with a considerable margin of safety) the strains which will come upon them, that the inferior quality is never detected or is considered of no consequence; sometimes, also, secondary reasons are the cause. Archi-

Castings made thick rather than good.

tectural outline, the difficulty of casting large thin pieces, a thickness to allow for safety in carriage or for the wasting by rust, are, rather than any precise strain to be borne, the circumstances which often guide the designer, who gives more thickness than would be necessary for the ultimate purpose if good quality iron were used. For castings exposed only to compression, the strength in this respect of even the commonest pig-iron may be sufficient. And even in such castings as girders, and long columns, exposed to transverse strains, architects and engineers often consider it easier to allow ample form and thickness than to incur the trouble and expense of tests necessary to

Deterioration of English iron.

ensure a good quality. It is to this indifference, and to the measuring of cheapness by price alone, that the degradation of quality which has undoubtedly taken place in some kinds of English pig-iron is mainly due. For the parts of engines or machinery, for pipes subject

See PIPES, *page* 648.

Tenacity of iron.

Method of testing.

Cinder iron.

The beam test.

See COLD-BLAST, *page* 538.

to high pressure, and for other uses where the iron is exposed to active and percussive strains, the higher qualities become of vital consequence. For purposes such as these, if there is any doubt of the quality, the tenacity or resistance to tension of the iron should be tested. From 5 to 14 tons per square inch of sectional area are the wide limits of strain which different kinds of cast-iron will endure. Resistance beyond 8 tons may be considered as exceptional, it being obtained by special methods for particular purposes, such as for guns. For the iron of commerce a tenacity of from 5 to 8 tons is usual, and some strain between 6 and 7 tons is often specified as a minimum. Up to a strain of 2½ tons there should be no loss of elasticity, i.e. of the power of recovery to the original form when the strain is removed. A working strain of 2 tons for iron of ordinary quality is safe for steady loads, but where the iron will be subjected to percussion, only 1 ton should be allowed. A usual method adopted by engineers for testing cast iron, is to try it in the form of a girder or beam, from the centre of which is suspended a weight, the load which is borne before fracture denoting the tenacity and toughness. A solid bar of rectangular section 2 inches deep, 1 inch wide, and 3 feet 6 inches long, is generally employed as a standard size convenient for comparison. The bar is laid on bearings 3 feet apart and loaded in the middle till it breaks; from 22 to 36 cwt. expressing the wide range of quality in British-made irons: a strength beyond 32 cwt., though sometimes obtained, being outside the ordinary range of the irons of commerce. The lower load generally indicates that the iron has been made from one inferior ore, or that there has been a large admixture of cinder iron, puddling-furnace slag, or similar refuse, which by the aid of the hot blast can be converted into pig-iron. A breaking load of 25 cwt. can be usually endured by bars made from ordinary pig-iron, and this quality is sufficient for thick columns, short stanchions, or similar castings, exposed mostly to compression. A test load of 28 cwt. is often adopted by engineers, because while it ensures a superior quality it is not so high as to limit greatly the competition in the supply. There are few kinds of hot-blast pig-iron made from any one kind of ore, which when re-cast will endure 28 cwt. on the test bar, but by the judicious mixture of two or more kinds 30 cwt. may be attained; and this load is often specified for high-pressure pipes or machinery castings. Higher tests may be obtained from cold-blast pig-iron, or from certain mixtures, but these are seldom demanded except for special purposes, as it

Exceptionally high tests. generally costs more than the mere comparison by extra strength would justify.

But while for a home trade the cheapest pig-iron may find the readiest sale, the conditions are greatly altered when pig-iron is **Pig-iron for export.** bought for export to distant countries. Cleveland pig-iron is exported in large quantities from England to the Continent for manufacture into rolled iron, and hæmatite pig-iron is exported for steel-making, **Foundry iron.** but Scotch iron is generally chosen for export for foundry purposes to countries beyond Europe. The choice of pig-iron for export is determined greatly by the contiguity of particular districts to the **Inland-made iron burdened with carriage to port.** port of shipment, and it is because the cost of inland carriage bears a high proportion to the value of the iron and to the sea freight, that the products of the blast furnaces in the Midland districts cannot compete with iron made on the sea-board. This limits greatly the export of pig-iron from Staffordshire, Derbyshire, and South Yorkshire, and gives a corresponding advantage to the Cleveland and **Freight charges common to all kinds.** Scotch irons. As, however, the cost of freight, duty and other charges in the importing country are assessed by weight, and as these expenses are in the aggregate great in proportion to the first cost of so cheap a commodity as pig-iron, it is evidently undesirable to attempt a saving by choosing an inferior kind, unless—for the pur- **Best is cheapest.** *See page 448.* pose in view—the quality is of very little importance. Thus, while it would be wasteful to buy high-quality pig-iron for casting into fire-bars or balance-weights, it is generally profitable to select a good quality for engineers' foundry purposes. Scotch pig-iron is **Imported iron mixed with scrap or native iron.** frequently imported into foreign countries to mix with native iron of inferior quality, and also in many cases with scrap cast iron, and high-priced cold-blast iron is also bought in small quantities. The quality of the local irons of course goes far to determine the kind of imported iron to be selected. The kind of castings to be made, the cost of freight, the duty and how it is assessed, are also important incidents to be considered.

Engineers and iron-founders who import pig-iron naturally acquire **Special kinds found suitable.** by experience a knowledge of their comparative values; and those who are thus informed regularly specify the brands which they consider will suit them best. But for the reasons already stated, the quality of iron produced in any particular district is liable to variation; and a knowledge of these changes and the ability to take advantage of them, are niceties which pertain to those who confine themselves especially to this one branch of the iron trade.

Hæmatite iron. *See page* 381.
Ingot-moulds.

Pig-iron of special quality, such as the hæmatite from Cumberland, is exported for steel-making; and this metal is sometimes sent out in the form of ingot-moulds to steel works, because of its ultimate value as scrap-iron for remelting when it has served its first purpose.

Steamers for carrying iron.
Iron carried as ballast cargo.
Iron and coal together.

Complete cargoes of pig-iron are conveyed coastwise and to Continental ports; and powerful, strongly-built steamers are specially constructed for carrying such dead-weight cargoes; while for ocean voyages, sailing vessels are most often employed. But an entire cargo of pig-iron involves high rates of insurance, especially in winter seasons. Pig-iron is often utilised as weight or ballast cargo at the bottom of a vessel which is to carry lighter merchandise above, and small quantities of 10 to 50 tons are often shipped to complete or adjust a miscellaneous cargo. A shipload composed of pig-iron at the bottom, and coal or coke above, is not uncommon, especially in sailing vessels.

Weight of iron pigs.

Pigs of iron weigh from 80 lbs. to 112 lbs. each, and, as preparatory to melting or for convenience in inlaid carriage, can be broken by a sharp blow with a sledge hammer, a small steam-hammer being sometimes provided for the purpose where the quantity is large and frequent. For making into malleable cast iron and other purposes where the melting is performed in crucibles, light pigs of from 20 lbs. to 60 lbs. are usual.

Rolled iron.
Subdivisions of manufacture.

Rolled iron (called malleable iron in some districts) as used by engineers may be divided into the following classes:—Rails, plates, sheets, bars, L bars, T bars, channel ⊔ bars, I joists, Z iron, bulb iron, hoops; numerous other special forms of iron being made for various purposes. The natural tendency of trades towards subdivision takes effect in the iron trade as elsewhere, and each of the classes enumerated above forms a specialty of manufacture separate from the other; for although certain makers do at the same works roll bars and plates, or joists and L bars, yet, owing to various economical reasons, such as the contiguity of suitable materials, facilities for delivery to the consumer, and other circumstances, the great bulk of each class is made at those works where little else than two or three of the various classes are produced.

Changes in the iron trade. *See* STEEL, *page* 556.

The trade has undergone great changes since 1860, partly owing to alterations or improvements in the processes of manufacture, partly also to the new localities into which the trade has spread, but above all by the growing use of Steel, which so largely supersedes iron.

New ironworks established on the Continent.

The ironworks which have been established in Germany, France, and Belgium, not only produce what had formerly to be imported thither from England, but compete with them in supplying other countries.

Trade-marks on iron.

See page 428.

The trade-marks or brands of old-established makers in England still, however, maintain their reputation, and—by the protection they afford to purchasers, especially to those abroad, who have found by experience what quality is associated with these brands—command a higher price than iron unmarked or with brands of less repute. This difference in price is, in effect, a bonus or a premium of insurance paid by the purchaser to avoid doubt as to what he is buying.

Old monopolies superseded.

But although a preference is still shown for the iron of particular makers, the localities having traditional reputation can no longer maintain as exclusively as formerly the monopoly they have had in the manufacture of iron, and the condition of quality as ascertained by specific tests tends to put different makers on a level.

Definition of quality.

See also page 554.

Terms such as "Best," "Best Best," "Best Staffordshire," though they may convey a definition of quality to those immediately concerned, and in regard to the iron supplied by well-known makers, are not accepted as sufficient by purchasers generally.

"Extras" on rolled iron.

Current prices conditional on size and weight of pieces.

Another condition of the trade in rolled iron, which is becoming gradually altered, is that of "extras." The current rates for rolled iron are based on certain accustomed conditions as to shape, dimensions, and weight of each piece. If anything outside or different from these conditions is required by the purchaser, extra prices are charged which in some cases bear a high proportion to the nominal cost of the iron. Makers have each their own rules, and there is a general uniformity throughout each district, though the rules in the different districts such as "Staffordshire" or "North Country" do not exactly coincide.

Limits extended or conditions relaxed.

As improved or more powerful machinery is established, the limits within which the ordinary current prices prevail are extended, and in several instances Continental makers have led the way in such concessions. The rules which apply in regard to extras are approximately stated on pages 551 to 555 against each kind of iron, but these rules are subject to variation in special cases,

Prices modified in favourable cases.

for although price-lists are printed and rules established for extras, an ironmaster will not always offer such low rates in a price-current or in answer to a general inquiry, as he will when he has presented to him a specification containing the sizes, quantities, and quality of iron actually required, with the periods and conditions of delivery and

Rules as to extras.

Functions of iron merchants and factors.

payment. He is then able to judge how far such an order will suit him at the particular time; and if it is suitable, or if it be a large order, or if his works are not well employed, then in many cases he will relax the ordinary rules, and offer prices more favourable to the purchaser than the mere current price and the nominal regulations as to extras would afford. It is the function of the iron merchant or factor to act upon these circumstances, and where a miscellaneous list of plates, bars, or other kinds of iron is presented by a purchaser, to divide it, and to obtain each kind from the manufacturer best able to supply it. An acquaintance with the capacity of different rolling-mills, and with the special facilities of each for making large, long, small, or heavy pieces, often enables the factor to supply a purchaser more favourably than can any one manufacturer.

Qualities of iron tested.

Tensile strength, how measured.

Elastic limit in iron.

About one-half the breaking limit.

Ductility of iron.

Usual ductility.

The tests of rolled iron are generally directed towards ascertaining tenacity, toughness and ductility. The tenacity or power of resistance against tension is in England and the United States expressed in pounds or tons per square inch of sectional area of the piece operated on (on the Continent in kilogrammes per millimetre), and the different qualities of iron rolled in England have a minimum strength of 17 tons per square inch (26·7 kilogrammes per millimetre) and a maximum of 25 tons per square inch. The elastic limit of the iron is, however, that which determines its value for most purposes, as after the strain on iron passes beyond this point, permanent distortion and rapid extension take place. The *limit of elasticity*, as it is called, is that amount of strain which the iron will undergo and still return to its original length when the strain is withdrawn; and this limit varies from 30 to 50 per cent. of the breaking strain. Thus, an iron bar which will withstand 22 tons per square inch before fracture, will, if it be of good quality, return to its original length after a strain of 10 or 11 tons has been imposed. After this limit of elasticity has been reached, what is called *permanent set* commences, and the iron does not return. The ductility of the iron is shown by its elongation under tension, and in a piece of iron one foot long pulled asunder this elongation varies from ½ in. to 2½ in. The percentage of elongation is greatest in short test pieces. For ordinary structural purposes from ¾ to 1 in. elongation per foot denotes a suitable quality, but from iron piled, hammered and rolled from good scrap-iron, or otherwise specially prepared, 2 in. or more is obtainable. A greater ductility is not desirable for most purposes, if the iron is tough and elastic enough to withstand sudden or

Tests varied to suit purpose in view.
See PLATES, *page* 549.

Farnley and Lowmoor iron.
See also BARS, *page* 554.

percussive strains without fracture. There are other methods of ascertaining the quality of the iron, the choice of test being determined by the purpose for which the iron is to be used. Thus, for the shackles and draw-hooks of railway trains, and for pit cages in mines where life is at stake, iron is preferred to steel by many engineers. It is for such purposes that "Best Yorkshire" iron, such as Farnley or Lowmoor, is used, at a cost about double that of good ordinary iron.

Iron for horse-shoes.

Tensile tests misleading unless toughness ensured.

A blacksmith will, by breaking or bending iron, soon ascertain whether it is suitable for his purpose, tests of this kind being sometimes specified either exclusively or in addition to tensile strains. The process of making horse-shoes is generally considered a fair test of quality, the bending, shearing, fullering (cutting close to the side), punching of nail-holes, and other manipulation of the iron revealing any hidden seams or cracks; the same result occurring in the numerous engineering forgings where flanging, bending and side-cutting are necessary. It may be said that a tensile test unaccompanied by other conditions is misleading, as extreme strength in this respect may be obtained from brittle iron having a low elastic limit. As above mentioned, the percentage of elongation varies with the length of the test pieces, and some engineers generally prefer to measure the ductility of rolled iron by the reduction of sectional area which the stretching causes at the place of fracture, and from 5 to 20 per cent. is the reduction from the original area which the different forms of iron rolled for structural purposes exhibit. In England, for the highest quality of structural ironwork, the following tests are specified; but in most cases, the test specified for L iron is considered sufficient for the bar-iron also.

Tests usual in England for structural iron.
See BRIDGES, *pages* 145 & 151.

	Tension.		Reduction of area at the place of fracture.
	Tons per sq. in.	Kilos. per sq. mm.	
Bar-iron	23	36·1	20 per cent.
Angle-iron	22	34·6	15 ,,
Plates (along the fibre)	21	33	10 ,,
Plates (across the fibre)	18	28·3	5 ,,

Best Yorkshire bar iron.
See page 554.

"Best Yorkshire" bar iron (of sections not exceeding two square inches) will endure 24 tons per inch, and show a reduction of area at the place of fracture of 45 to 55 per cent. In thick bars which have not received so much work in course of manufacture, the strength and ductility are rather less, and bars above 5 inches diameter made under the steam hammer without rolling are slightly harder and less ductile than smaller sizes of rolled iron. Best Yorkshire iron weighs about one per cent. more than ordinary iron.

Obvious defects in iron.

Seams and imperfect welds.

There are some defects in rolled iron which are obvious on inspection: thus, cracks or seams may appear where the iron laminates, showing that, in the process of hammering and rolling, the various pieces in the original pile have not been properly welded, and that dirt or scale remains in the interstices. Iron which looks clean and sound when cold, may reveal flaws and cracks when heated and twisted on the anvil. Some iron (generally owing to the sulphur it contains) is "red-short," that is to say, it will not work well when hot, although when cold it may have a tough fibre. Cold-short iron (generally containing an excess of phosphorus) is brittle when cold, and though it may be worked successfully when hot by a skilful smith, it is useless for most engineering purposes.

Red-short iron.

Cold-short iron.

Export of iron.

Choice of quality.

Very high tests inexpedient.

It is not expedient, for reasons already adduced, to export iron of low quality; but except in special cases, such as when the cost of carriage, import duty, or other charges bears a high proportion to the purchase-money, and where, therefore, it is very important that the weight shall be as low as possible, it is not economical to demand a quality higher than is customary among makers of repute. If specially high qualities or exceptional guarantees are insisted on, the number of manufacturers who can and will compete is reduced, and the extra cost is more than proportionate to the advantage gained. In the case of wrought-iron for structures, such as bridges and roofs, it may be said broadly that if tests more rigorous than those tabulated on page 546 be demanded, an extra price has to be paid, greater than the extra advantage gained; but if only a higher breaking test be required, it can be satisfied at the expense of toughness; for, as just stated, by suitable material and methods of manufacture, a strong iron with a low elasticity may be produced as cheaply as iron of more moderate tensile strength having sufficient toughness. A skilful iron-maker can, if informed of the purpose for which the iron is required and the after treatment it is to bear, produce in many cases, even without extra cost, the quality which will meet these circumstances.

Strong iron without toughness

Iron made to suit purpose.

Cost and selling price, how determined.

The relative cost and selling price of different kinds of rolled iron are determined by various circumstances. Where the demand for any one kind is very great, certain economies are obtainable. Rails are an obvious instance of this, and so long as thousands of rails precisely alike were ordered at one time, every incident in the

See Steel Rails, *page* 660.

manufacture could be arranged in the most economical manner. Steel has, however, entirely superseded iron for rails.

Cost of process varies.

Examples.

Waste in cutting.

Some forms of iron demand a higher quality of raw material or more elaborate or expensive working than others. This is the case often with large thin sections. In other cases, although more trouble may have been bestowed on the working, the shape or thickness may not be favourable to good results. Thus, T bars, while about £1 per ton dearer than L bars, are not—the original material being equal—of such good quality, because the method of rolling T bars to give them their peculiar shape is not so uniform or effective as in the case of L bars. The hammering and rolling necessary for plates is more expensive than the same process for ordinary bars, and the plates will not endure such high strains; and as also there is some waste in shearing the edges of the plates to a clean and regular edge, they cost from £1 to £2 per ton more than the bars.

Iron made to order and not kept ready made.

Small quantities expensive.

Exceptional or peculiar shapes.

Limits competition.

Latitude necessary in choice of size.

The larger proportion of rolled iron used by engineers is made to order for each particular case, and except for miscellaneous smithing purposes, it is seldom kept in stock, either by the maker of the iron or the user. Where the quantity required of any one kind of rolled iron is small, there is sometimes more time and trouble expended in obtaining it than for a much larger quantity, because it is not always convenient at a rolling-mill to put the rolls of suitable patterns into operation. For the same reason it is desirable in making a design, to avoid exceptional or peculiar shapes, or even numerous sizes of iron. All the usual sizes of round, square or flat iron can be easily procured, but engineers who are furnished with the pattern-books of iron merchants or makers are too apt to consider that all the sizes or shapes in the book are equally obtainable, and in quantities however small. But unless the pattern-book be quite new, probably some of the shapes shown are obsolete or the rolls worn out. In other cases, the rolls for the exact pattern specified may exist at only one rolling-mill, or at mills making only a certain quality, and the purchaser may have no option but to agree to the price, quality and the period of execution demanded. An engineer in an iron and steel-making country can, as occasion arises, modify his design, or allow some latitude in regard to exact shape and size, so as to meet these difficulties; and an engineer or purchaser in an importing country should in ordering iron also allow some latitude in regard to modifications. Sometimes an engineer, in his endeavour to make his design as perfect or symmetrical as possible, will adopt sections of iron

Great variety increases cost.

If in small quantities.

Cost of new or altered rolls.

Irregular sizes to be avoided.

varying by fine gradations in different parts of a structure, or will have shapes exactly appropriate to the purpose in view. Moreover, to add to the difficulty, the quantity required of each kind may be very small. In such a case, unless some reasonable departure from the exact detail be permitted, much additional cost and very greatly extended time in execution will be incurred. If, however, the quantity required of any sort of rolled iron be large, any existing section may be chosen, as makers will be glad to put in operation the necessary rolls, and even to provide new rolls, which can generally be made or adapted at a cost of from £20 to £50. In any case it is economical to adopt usual sizes of iron, and to avoid small fractional dimensions; plates within the limit of size described on page 551, so as to avoid extras; L or T bars of even figures, such dimensions as 3 × 3, or 3 × 4, or 3½ × 3½, being preferable to irregular or unequal sizes, such as 4 × 3¾, and 3 × 2⅜. On the other hand, when the exigencies of design demand it, it is well to take advantage of the patterns that exist, and the preceding remarks are only directed towards a prevention of unnecessary expenditure where small quantities are required and no exact adherence to precise dimensions is really necessary.

The different classes of iron enumerated on page 543 may be described as follows.

Rails.

See pages 559 *&* 660.

Rails, as forming a larger tonnage than any other kind of rolled iron, might, up to the year 1875, have been placed first in order of importance, but everywhere the introduction of Steel rails has terminated this branch of the iron trade. Rails are fully described in later pages.

Plates.

Lowmoor and other high quality Yorkshire iron.

How made.

For what purpose.

Will endure severe strains.

Plates are generally classified as for boilers, bridges, tanks, and ships, and their quality may be broadly placed in the same order. First in quality come the celebrated Yorkshire plates made at Farnley, Lowmoor, and other works in the locality, and these stand apart from all other kinds. The high quality of these plates is obtained partly by the use of special material (refined cold-blast pig-iron), with non-sulphurous coal and coke, and also by the elaboration and care in the manufacture. These plates are used for the fire-boxes of boilers, where the intense heat and varying expansion would soon destroy inferior iron; for the entire substance of small boilers bent to sharp curves or subject to high pressure; and generally for places where iron has to be flanged, bent, dished, or twisted in a manner which only the best iron can safely withstand. Although these high-priced plates have been largely superseded by steel, they

Price of Yorkshire iron plates.

Charcoal iron.

Coal substituted for charcoal.

are still preferred by some engineers for the furnaces of locomotive boilers as being more trustworthy, especially with bad water. The price of these high-quality plates is generally double, or more than double, that of ordinary boiler plates of iron or steel. For certain purposes, such as for the wrought-iron domes of locomotives, for superior tin plates, and for conversion into crucible steel, iron made with charcoal fuel was formerly preferred to the special brands just described. The freedom from sulphur which the use of charcoal ensures, and the method of manufacture, give a peculiar softness and homogeneity otherwise unattainable. Charcoal iron has been almost entirely superseded by steel.

Boiler plates.

Qualities needed.

Bridge plates.

Tensile strength.

See page 546.

Tank plates.

Ship plates.

Inferior quality.

After the high-quality Yorkshire plates, boiler plates come first among ordinary irons, and are equal to a breaking strain of about 22 tons with the fibre, and from 18 to 19 tons across the fibre, with a ductility which gives from 10 to 15 per cent. reduction of area at a place of fracture. According to the care bestowed upon them in manufacture they will withstand the constantly fluctuating strains caused by alterations of temperature, and may be bent to the curve of a cylindrical boiler and punched without damage. The iron plates used in bridges, girders and similar structures should be of a quality good enough to endure without damage the punching, shearing, and other treatment in manufacture, and to withstand without rupture a sufficient strain. The tensile strength of iron bridge plates usual in England is from 20 to 21 tons per square inch with the fibre, and from 17 to 18 tons across the fibre, with a ductility which gives from 8 to 10 per cent. reduction of area at the place of fracture. Such plates cost £1 per ton less than boiler plates. Toughness is of more importance than a high breaking strain, especially in the case of railway bridges which are subject to heavy percussions. Tank plates may be classed in regard to quality with bridge plates, any superiority they have being incidental to their lesser thickness and the greater working necessary in their production. Ship plates are, as a rule, inferior in quality to the bridge plates described above, and cost from 10*s.* to £1 per ton less. There is no good reason for this, and where no stipulation is made in regard to quality, and where mere cheapness of price is allowed to prevail by open competition among manufacturers, a ship and a bridge would probably alike be made of similar inferior iron. But the stipulations as to quality usual amongst the principal bridge engineers are higher than those by which a ship can obtain admittance to the usual desired

Steel and iron for ships.

classification at Lloyd's registry. The use of Steel for shipbuilding is raising the standard of quality, and iron is now rarely used except for certain parts of the deck and framing where it is deemed more suitable than steel.

Extras on plates.

The extras on iron plates may be approximately stated as follows, though some makers concede rather greater latitude. If not exceeding 4 cwt. (in some districts 5 or 6 cwt., and in the north of England even 9 cwt.) per plate, 40 square feet superficial area, 15 feet length, or 4 feet width, the ordinary current prices are charged. For every 5 feet additional length, an extra price of 20*s.* per ton; for every 6 inches in width beyond 4 feet, 10*s.* per ton; for any weight in excess of the standard up to 8 cwt. 20*s.* per ton; and a further extra of 20*s.* per ton for every 4 cwt. from 8 to 20 cwt.; or 20*s.* per ton for every 10 ft. or part of 10 ft. beyond 40 superficial feet. Plates cut to irregular shapes are necessarily expensive, and if sizes or weights exceptionally large are wanted, special contracts must be made with the few makers who have machinery capable of producing them. Plates, after they are rolled, are sheared on all sides to a size which will include the desired dimensions, but it is not usual, without special stipulation, for the plates to be cut at the rolling-mill exactly true to absolute dimensions. Such work is part of the process of manufacturing the plates into articles of utility. At many rolling-mills, plates up to 12 in. wide can be obtained rolled as bars, that is, with edges true and square enough to obviate the necessity for cutting or planing. Indeed at some rolling-mills with powerful machinery, plates even 30 in. wide are rolled as bars, and sold at the ordinary price for plates. The use of such improved machinery is tending to alter the old-established rules for extras as just described.

Limits of length, width and weight.

Irregular shapes.

Plates sheared to exact sizes.

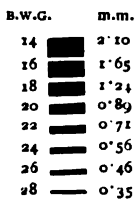
Plates rolled as bars.

Limits of width.

Thin plates.

Plates less than ¼ in. thick cost from 5*s.* to 10*s.* per ton more than those ¼ in. thick and upwards, and these thinner plates are used principally for tanks, gasholders, and similar purposes. Below $\frac{3}{16}$ in. thick the word plate becomes merged in that of *Sheets*, and among English makers the thickness was formerly not measured by fractions of inches, but by the Birmingham Wire Gauge (B.W.G.).

Sheets.



94.

B.W.G.

This gauge was established by makers in a certain district, but as it was only customary and was not always uniform or recognised in other districts, it proved a source of inconvenience to manufacturers and merchants. The need for some established standard, and the reluctance to adopt the metrical measures accepted in most other countries,

Imperial Standard Gauge.

B.S W.G.		mils.	m.m.
14	=	80	2.03
15	=	72	1·83
16	=	64	1·62
17	=	56	1·42
18	=	48	1 22
19	=	40	1·02
20	=	36	0·91
21	=	32	0·81
22	=	28	0·71
23	=	24	0·61
24	=	22	0·56
25	=	20	0·51
26	=	16	0·45
27	=	16·4	0·42
28	=	14·8	0·37

led, as a compromise, to the permissive use of a new "Imperial Standard Wire Gauge," in which the divisions correspond with a certain number of "mils" or thousandths of an inch. The numbers range very nearly with those of the B.W.G., and the differences are best compared by reference as to a common standard to those metrical measures to which they each most nearly approximate. Those most usually employed by engineers are shown in the annexed tables. But where difficulty or doubt arises, the desired thickness of rolled iron, steel, or other metals may be best ensured by specifying the weight per square foot in pounds, or per square metre in kilogrammes.

Annealed sheets.

Russian sheets.

How made.

How used.

Down to and inclusive of No. 20 B.W.G. (0·89 m.m.) sheets are known commercially as *singles*; from No. 20 down to and including 24, as *doubles*; and below this as *lattens*, the price rising in corresponding order. Besides this, if sheets are wider than 3 ft. or longer than 8 ft., or in any way have a larger area than 24 superficial feet, an extra price is charged, which mounts up from 10 to 40 shillings per ton very rapidly as the area is increased. Sheets after they are rolled are generally annealed to render them ductile, and are then in some cases re-rolled to give them a smooth surface. Sheet iron of very high quality is made in Russia, charcoal not only being used as fuel for the ordinary purposes, but again after the sheets have been rolled; numerous sheets being piled together cold with charcoal between them, and hammered in a peculiar way. Sheets so made have a smooth glossy surface, unattainable by other means, and are not so susceptible to rust as ordinary sheets. They are used for the outer casings of locomotive boilers, as a casing to the wood lagging of steam cylinders, and for other purposes where a very smooth surface is required. In Russia they are even used—generally unpainted—as roof covering. They cost much more than ordinary sheets.

Corrugated sheets.

Advantages.

Sizes of flutes.

Though sheets are manufactured into innumerable articles of utility, they are of interest to engineers chiefly because of their use as galvanised corrugated roofing sheets, of which very large quantities are made in England. The galvanising protects the iron from corrosion, and the corrugations give great strength and stiffness to the sheets: the depth of flute determining the strength. In England the usual widths of the fluting are 3 in. and 5 in., and the depth ranges from one-fourth to one-fifth of the width. But as the strains during the process of corrugating test the quality of the iron in proportion to the depths of the flutes and the thickness of the iron, there is a tendency to make cheap sheets with shallow flutes, while engineers who want sheets for structural purposes often specify deep flutes. Galvanising is an arbitrary and misleading name which has been applied to the process of coating iron with zinc or spelter. The value of the galvanised sheets depends upon the quality of the iron, the quality of the spelter, and the care with which the process is performed. Although a certain minimum quality of iron is absolutely necessary to allow sheets to be rolled of the required thinness, yet, with this proviso, inferior sheets are sometimes made, which, if carefully examined, will be found to have minute cracks or a blistered surface. Sheets of this kind will not hold the spelter properly; cannot endure the corrugation without risk of damage, or, if safely corrugated, will not endure curving afterwards; and when exposed to the weather, soon become rusty. Charcoal-iron sheets for galvanising are not an ordinary article of commerce. The sheets that are sold at extra prices by manufacturers for galvanising and other purposes, under the name of "charcoal sheets," are generally made of steel.

Galvanising.

Value of, how determined.

Inferior sheets.

Charcoal sheets for galvanising.

Galvanised corrugated sheets are made of various thicknesses, from No. 16 B.W.G. to 28 B.W.G., but for roofing and other ordinary purposes sheets thicker than 18 B.W.G. are seldom used. This is the gauge preferred by engineers in England for first-class work, but the sheets generally exported are of the thinner gauges, and in the English colonies especially Nos. 24 to 28 are in constant demand, as the thinner sheets, though dearer per ton, cover more surface. The price of galvanised sheets, depending as it does on the current value of spelter as well as of iron, has no uniform relation to the prices current for iron, but assuming that spelter is selling at £20 per ton, then when boiler plates are selling at £10 per ton, galvanised corrugated sheets from 16 to 28 B.W.G. would sell from £14 to £20 per ton, the thinner sheets being the dearest, not only because the thinner iron is the more expensive, but because in these sheets the proportion of spelter to the weight of iron is the greater. On the other hand, if deep flutes be required, the thick sheets will not so readily bend as thin sheets, and tougher and dearer iron becomes necessary. High-quality annealed sheets, galvanised and cold rolled but not corrugated, are made for working into articles of utility. Such sheets cost from £5 to £12 per ton more than ordinary galvanised sheets. When for use by the first purchaser in the country of manu-

Usual thickness of galvanised sheets.

See ROOFS, *page* 871.

Thin sheets for the colonies.

Price of galvanised sheets.

Depends on price of spelter.

Packing for shipment.

facture, galvanised sheets are sometimes merely bundled together; but for shipment it is usual to pack them in cases, the cost of which adds from 15*s.* to £1 per ton to the price. But for protection from sea water, and in order to preserve the good appearance of the sheets for re-sale, the sheets are often enveloped in felt wrappers, sealed with pitch, and then packed in cases.

Skill in making galvanised sheets.

Has led to making bad sheets.

Inferior sheets soon wear out.

Since the process of galvanising was first introduced, manufacturers have acquired by experience increased aptitude and skill, which have enabled them to produce good sheets at a less cost than formerly. But, unfortunately, increased knowledge has allowed the production of sheet iron and galvanised sheets, which, while of an inferior quality, look good enough to be saleable. There is no case where cheapness obtained by inferior quality is a falser economy than with galvanised iron, for the deterioration, when it commences, is in such sheets so rapid as to be out of all proportion to the first saving which may have been effected in price.

Bar iron.

Merchant-bars.

Well known brands.

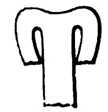
See Trade-Marks, *page* 428.

See page 546.

95.

Forge test hot.

Square, flat, round, and other forms of iron used by blacksmiths, and included in what are known as *merchant bars*, are made of various qualities, a proper choice depending of course mainly on the purpose for which the iron is required. A foreign purchaser who wishes to be safe can, as already stated, protect himself by stipulating for the brand or trade-mark of a well-known maker. Unbranded bars may usually be taken to be of the very lowest quality; bars branded only with a crown may be deemed the starting point for a quality suitable for ordinary merchant trading or cheap smithing purposes. The next highest quality is stamped "best," and so on to "best best" and to the special brands of celebrated makers, the highest quality being that already described as "Best Yorkshire," which costs double the price of ordinary bars. This iron is used where resistance to sudden shocks is necessary. Thus, for the draw-bars and shackles of railway engines and carriages such iron is used, where steel would not be trusted, and in preference to all other kinds of iron. Next in order to this special quality are bars capable of enduring the following tests, which can only be borne by first-class iron, such as is sold by manufacturers of repute. Samples should be notched and bent back cold to show the fibre of the iron. Bars marked B B or "best best" should endure 22 tons strain per square inch with the fibre of the iron. Square or round B B iron being forged hot may be punched with a punch one-third the diameter of the bar, at a distance of 1½ diameters from the end of the bar, and a second hole, at right angles to the first, at three diameters from the end of the bar. The holes may then be drifted out to 1¼ times the diameter of the bar, and the sides of the holes being then split, the ends must admit of being doubled back without fracture. Flat bars not exceeding ¾ in. thick may be bent with the fibre to a radius of 2½ times their thickness without fracture. Bars branded B or "best" may be punched as above, and drifted out to the diameter of the bar, and the sides of the holes should admit of being bent outward without fracture. Flat bars not exceeding ¾ in. thick may be bent, with the fibre, to a radius of three times their thickness without fracture, and should endure punching and drifting also.



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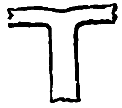


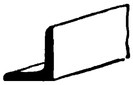
97.

Ordinary sizes of bar iron.

Extras, how charged.

Limits of flat bars.

Round and square merchant-bars of all sizes from ½ in. to 3 in. are sold at ordinary rates; but below these dimensions the rates increase. Above 3 in. prices also increase rapidly, so that bars 6 in. diameter cost from £3 to £5 per ton above the ordinary rates; the number of ironworks with machinery capable of rolling such large sizes is much less than for ordinary bars; and sometimes such bars are forged under the steam-hammer. Whatever be the thickness, if the size or length involve a greater weight than 4 cwt. (in some cases 6 cwt.), extra rates are charged. Flat bars from 1 in. × ¼ in. to 6 in. × 1 in. are usually sold at current rates, and extra prices are charged for larger or smaller sizes, but wider bars, up to ¾ in. thick, made for use as plates, can be purchased at the price of plates.



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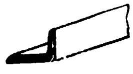

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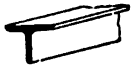


100.

Extras, how charged.

Limits of length.

Bars of L or T form are rolled of all sizes, from 1 in. wide to 8 in. wide, but the greater number of sections between these limits are of dimensions between 2½ in. and 5 in. If not thinner than ¼ in., sections as narrow as 2 in. can be purchased at the current rate, but if thinner than ¼ in., then from 10*s.* to 20*s.* per ton extra is incurred. The ordinary current price is paid for all sections from 2 in. wide up to and including 8 united inches. That is to say, a section of 3 × 5 in. or 4 × 4 in. will, as not exceeding 8 in., be deemed ordinary, but for every inch beyond 8 in., an extra of about 10*s.* per ton is imposed; and moreover, if by reason of the thickness of the bars, a weight of about 4 cwt. is exceeded, an extra charge per ton of about 5*s.* is made for every cwt. in excess. Above a certain limit of length (which ranges at different rolling-mills from 20 to 40 ft. for L bars, and 20 to 30 ft. for T bars) about 5*s.* per ton is charged for every 5 ft. of extra length. The exigencies of transport generally render pieces longer than 30 ft. undesirable, but where the total length does not exceed

Limits of thickness.

40 ft. it may be cheaper to make the bars in one length, and to pay extra carriage rates, than to divide and joint the bars. As the sizes become larger, so also must the thicknesses be increased, as thin iron becomes cool too soon while passing through the rolls. Thus bars 5 in. wide should not be thinner than $\frac{1}{2}$ in., 4 in. bars than $\frac{3}{8}$ in., 3 in. bars than $\frac{5}{16}$ in., and so on. These limits may, however, be slightly overstepped by care in rolling, for which extra prices are charged.

Quality of L and T bars compared.

As stated on page 548, the iron in L bars is generally better, and of more uniform quality than that in T bars, as the grooves in the L bar rolling-mill are arranged so that the pressure upon each side is more equally applied than is the case with T bars. On the other hand, a T section is more symmetrical than an L section, and affords more convenient opportunities in a structure for joints and connections. L bars are cheaper than T bars, partly because the process of manufacture is slightly easier, but mainly because the quantity manufactured is very much greater, rendering special arrangements feasible, and increasing the competition of makers.

See ROOFS, *page* 864.

Straightening and cutting bar iron.

Bars of all kinds as sold from the rolling-mill are only approximately straightened and are seldom cut to exact lengths, these being operations belonging to the boiler-makers, bridge-builders, or others who make them into articles of utility. Iron joists were, during the years following 1885, almost entirely superseded by steel.

Steel.

How it differs from iron.

Steel has certain main qualities which distinguish it from iron.

(1) Its homogeneity. Steel, when "converted" from iron is cast, while molten, into an ingot, and, whatever the after processes of hammering, rolling or tempering, retains this quality, in which it differs from fibrous iron.

(2) Its superior strength, which can be varied according to the degree of ductility required, from mild steel having a tensile strength of 25 tons per inch to the hardest steel equal to 60 tons per inch.

(3) Its durability or resistance to wear or abrasion.

(4) Its capacity for being tempered, although for this latter purpose the mild steel used in structures is not suitable.

Advantages afforded by steel.

It is its strength which renders steel suitable for structures (ships, bridges, roofs, &c.); its strength and ductility, which adapt it for boilers; its durability against abrasion, which makes it so valuable for rails, railway-points, wheel-tires, toothed wheels; and its capacity for being tempered, which distinguishes it from all other materials as alone suitable for cutting tools and springs.

Chemical composition of steel.

Carbon in iron and steel.

Mild steel.

It is unnecessary here to describe the chemical composition of steel, except in regard to those main points which determine the choice of kind and quality for particular purposes. The principal chemical difference between iron and steel is in the amount of carbon they each possess, steel in this respect coming between cast iron and wrought iron. Cast iron contains from 2 to 4 per cent. of carbon, wrought iron from 0·012 to 0·3 per cent., and what may be termed—for want of a better designation—steel proper, has, according to its kind, any proportion of carbon between 0·2 and 1·5 per cent. What is called mild steel, or ingot iron, contains from 0·05 to 0·18 per cent., chemically, much resembling wrought-iron. Mild steel is sometimes sold as iron, and as in some cases it is important to ensure the use of real wrought iron, the essential difference must be recognised that iron has been puddled and is fibrous, while steel having been made from a cast ingot is homogeneous, the choice, in this regard, between iron and steel depending on the purpose in view.

Bessemer steel.

Excess of phosphorus.
See page 547.

Non-phosphoric iron ore.
See page 381.

Basic steel.
See also page 384.

Up till about the year 1860 steel was made by elaborate processes from wrought iron of high quality by adding to it a certain quantity of carbon. Bessemer's inventions introduced the much simpler method of entirely decarbonising molten cast iron by forcing a blast of air into it and then giving back to it a sufficient amount of carbon, together with manganese, to produce steel of the desired grade. With the exception of the hæmatite iron ore found in the West Cumberland and Barrow district, British iron is not pure enough to make Bessemer steel of the ordinary kind, as the phosphorus in the iron, which is not eliminated in the converting process, renders the steel "cold short," or brittle. The supply of English pure iron at a moderate cost is not sufficient, and non-phosphoric ore is imported from abroad, mainly from Spain, from the north coast of Africa, and from Elba, large shipments from these places having also been made to the United States, where most of the iron ore has the same defect of excessive phosphorus. By the subsequent Thomas-Gilchrist inventions, known generally as the basic method—in which, by means of lime, the phosphorus is eliminated during the converting process—steel can be made from ordinary iron, and this basic method is more or less used in different districts and countries, according as the alternative expense of bringing pure ore from a distance renders it desirable. Thus it is more used in Germany than in Great Britain, because in the latter country ore from the Barrow district and from Spain is cheap.

Open-hearth steel.

Soon after the Bessemer inventions, the Siemens "open-hearth" process was introduced. By this plan and by subsequent modifications of it, cast iron is decarburised by mixing with it wrought iron, or iron ore, while the cast iron is in a molten condition. The plan occupies about ten hours, as against twenty minutes by the Bessemer method, and this longer time affords facilities for testing the metal during its conversion, and of rectifying errors in the process. Open-hearth steel, like Bessemer steel, cannot be made of good quality from phosphoric iron; but the basic method has been applied to it also; and now by its means the ordinary native ores are utilised for "open-hearth" as well as for Bessemer steel wherever it is desired to save the cost of using pure iron.

Basic open-hearth steel.

Quality of steel, how specified.

In the purchase of steel some engineers prescribe the method of manufacture as well as the results; others stipulate only for the results, namely that the steel shall have a certain chemical composition and be capable of enduring specified mechanical tests to show tensile strength, ductility or toughness, according to the purpose in view. In the majority of cases, however, the mechanical tests are alone demanded, because these are what really concern the purchaser, and because such tests are supposed to be necessarily allied with a certain chemical composition of the steel. The double proof is demanded most often in the case of large purchases, where only a small proportion of the whole can be tested, and where, therefore, a chemical analysis serves as a useful check on the quality of the material—a check, indeed, which the manufacturer himself adopts for his own sake, whether specified by the purchaser or not. When, however, steel is purchased in a rough condition as material for further processes, such as in the form of ingots, blooms, or billets to be worked up into articles of utility by the purchaser, then mechanical tests are inconvenient or impossible, and chemical analysis is the only proof of quality available, except that afforded by the appearance of the steel and the absence of flaws. In contracts for ingots, blooms, or billets, the percentage of carbon is specified according to the purpose to which the steel is to be put, and in the case of purchases from abroad, the certificate of an independent chemist that the analysis is satisfactory is often required with each invoice.

Tests.

Chemical analysis.

Where required.

Chemist's certificate.

The experience in steel making has grown so rapidly that a preference for one system of manufacture over another is liable to be modified as improvements occur; but it may be said generally, that steel can be made by the Bessemer process of any desired grade and

Choice of steel.

Bessemer rails.

Basic process best adapted for mild steel.

for any purpose, the simplicity and speed of manufucture giving it a preference in the production of large quantities at a low price, while the certainty of quality is shown by the tests employed and the very trifling percentage of failures. As, however, the production with absolute certainty of exact grades of Bessemer steel demands skill and constant attention during a process too rapid to allow for corrections of error, some purchasers prefer to pay rather more for steel made by the slower open-hearth process, which affords time for tests during the conversion, and which, in the opinion of some metallurgists, gives a more certain uniformity than in steel made from one "blow" of a Bessemer converter, where—it is alleged—the ingots are not always uniform. Rails are exclusively made by the Bessemer process; but of steel for plates, bars, tires, springs, and other more expensive forms, probably more than half are made by the open-hearth method. Basic steel has not been accepted universally for the higher and more expensive purposes; but this disinclination is likely to disappear as experience proves the trustworthiness of such steel, and is largely due to the cheapness of ordinary steel made from pure ore. The basic method of manufacture shows to the greatest advantage in mild steel of low tensile strength, such as is suitable for boiler plates and for many purposes to which soft "ingot iron" is applied. On the Continent such ingot iron (*fluss-eisen*) is principally made by the basic method.

Classification of steel.

Hard steel for rails.

Carbon in rails.

See page 700.

101.

Hard steel for tires.

For engineers' purposes steel may be classified according to its hardness, tensile strength, ductility and capacity for tempering. The more the carbon the harder the steel, and from this point of view Steel for *Rails*, *Tires*, *Bridges*, *Axles* and *Boilers* may be cited as examples of different grades. Hardness against abrasion is the quality most desired in rails, so far as it can be obtained without brittleness, and this is found in steel having a tensile strength of 38 to 42 tons per square inch of sectional area. To obtain this quality nearly a half per cent. of carbon is given to the steel, the exact percentage ranging from 0·35 to 0·5. More than this would bring the steel further towards the condition of cast iron than would be prudent, and would render the rail unable to withstand the test of sudden impact by a falling weight. The toughness of railway tires is tested by bending them under a falling weight, and it is endeavoured to satisfy this condition and at the same time use steel or a maximum hardness to withstand abrasion. To obtain this combination, steel of not more then 30 tons tensile strength has been used. But while this quality was deemed satisfactory for some years after steel tires were introduced, a harder steel, equal to a breaking strain of 45 and even 48 tons per inch, is obtainable, and can be made within the limits of toughness required for the bending tests. Such tires command a higher price than softer tires, but only a few steel-makers can produce them. Not only an exact mixture of materials, but processes, more or less secret, of tempering have much to do with these results.

Amongst the advantages afforded by steel is the great facility with which it can be manufactured into pieces of large size and weight. Steel, when "converted," is run molten into ingots, and is afterwards squeezed, hammered and rolled into the desired form. Ingots can be made of any weight up to 50 tons.

Steel for ships and bridges.

See page 145.

For plates, bars and beams in ships, bridges and roofs, steel equal to a tensile strength of from 27 to 32 tons, with a ductility shown by an elongation of 20 per cent. in a length of 8 inches, is generally specified by engineers, though for parts of structures which will be subjected only to compressive stresses, harder steel up to 40 tons is sometimes permitted. In steel of all the above grades care must be taken in punching and shearing, because these operations tend to crystallise the metal immediately affected. Punching is prohibited by some engineers, but more often is permitted with the stipulation that punched holes must be drilled or rimered out, and sheared edges planed, so as to remove about one-twelfth of an inch of the metal. The annealing of steel restores the crystalline parts to their original condition, and when this operation is performed, the drilling or planing above referred to is not necessary. As the real value of either wrought iron or steel for such purposes as ships or bridges depends not only on its ultimate breaking strength, but on the limit of elasticity, steel has a special advantage because it has a much higher proportionate limit than iron. Thus, while iron equal to 20 tons breaking stress will have 10 tons as a limit of elasticity, steel of 30 tons can be produced with a limit as high as 18 tons.

Effect of punching on steel.

Elastic limit of steel.

See IRON, *page* 546.

Steel axles.

Steel for boilers.

For railway axles, which are subjected to severe bending stresses, steel of from 33 to 35 tons is suitable. Much softer steel is used for boilers; for though steel up to 30 tons might not be too hard for shell plates and the flat ends of boilers, yet for plates which have to be flanged or dished, softer steel of from 25 to 27 tons tensile strength, with an elongation of 25 per cent. in 8 in., is demanded—

such steel containing not more than from 0·05 to 0·1 per cent. of carbon.

Prices of steel and iron compared.

So long as the demand for steel was small and uncertain, prices could not be stated with the same precision as those of iron. At their first introduction steel plates for boilers and bridges cost double the price of iron plates, but this difference was soon reduced, and since 1885 steel plates, beams and bars cost only about £1 per ton above the price of ordinary iron. Steel bars of L, T, and the numerous other forms usual in rolled iron, cost about the same as steel plates, and as the demand for steel has increased the sizes and patterns have become as numerous as in iron. Large pieces are cheaper in steel than in iron, for the limits of size and weight within which current prices apply without extras are wider and much more in favour of the buyer in the case of steel plates and bars than in the case of iron. The manipulation of lumps of puddled iron, and of the slabs and blooms into which the iron is welded, before it takes the final form of plate or bar, becomes costly when a certain size and weight are exceeded. An ingot of steel, on the other hand, can be as easily cast five tons in weight as half-a-ton; no welding processes intervene, and the ingot is rolled down by machinery to its final form. The difference in these respects tells considerably on the price when plates or bars of half-a-ton or upwards are reached, the price of steel in such cases being less than those of iron.

Limits of size and weight.

Puddled iron costly in large pieces.

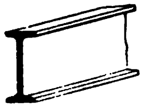
Steel ingots cheaper.

Steel plates.

In the manufacture of steel plates there are certain combinations of length, width and thickness which are easiest to deal with. It is not easy to roll thin plates of more than a certain area, because they cool rapidly in the process. Thus, while a plate ¼ in. thick would be supplied without extra charge up to about 800 lbs. in weight, one of ⅜ in. thick would be sold at the same rate up to 1000 lbs., and one of ¾ in. thick without extra charge for weight of 8000 lbs. But an extra rate is incurred when a length of 20 ft. is exceeded for ¼ in. thick, or when 26 ft. is exceeded for ⅜ in. thick, or 35 ft. for ¾ in.; and in regard to width, also, an extra is incurred for ¼-in. plates when more than 4 ft. wide, for ⅜-in. plates when more than 5 ft. wide, and for ¾-in. plates when more than 8 ft. wide. Beyond certain limits the extras for length, width and thickness may overlap or accumulate, and elaborate tables are compiled by manufacturers to show clearly to purchasers how to calculate extras. During the seven years 1892–98 the normal price at the works of steel plates ranged from £6 to £10 per ton.

Rules as to extras.

Steel joists.



102.

See also page 864. STEEL COLUMNS.

Steel joists are mainly used as floor beams or girders of small span, as cross-girders in narrow bridges, or as longitudinal rail-bearers in a bridge. They are also used—especially on the Continent—for the rafters of trussed roofs, where in England T bars or a riveted girder would be preferred. Steel beams are frequently riveted together to form composite stancheons or columns. As bulb beams they are an important part of steel ships and steamers.

Small and narrow sections cheapest.

Small and narrow sections, having a depth of from 4 in. to 7 in. and a width of from 1 in. to 3 in., are the cheapest, the price rising slightly up to sizes 9 in. deep and 4 in. wide. Beyond these sizes the price increases, so that joists or beams 12 in. deep and 6 in. wide would be from £1 to £2 per ton dearer; while if wider flanges be required, the price would be still higher, and the quality of the flanges probably inferior.

Limits of size.

Joists more than 15 in. deep can seldom be used with advantage, and above these dimensions riveted girders are in England generally preferred, though on the Continent sizes up to 20 in. deep are constantly used; while, as a *tour de force*, they have been rolled as deep as 1 mètre (39⅜ in.). In this case, by an ingenious machine with numerous rolls, the flanges are compressed as well as the web, and if such a method of manufacture could be applied to all joists, their quality and usefulness would be greatly increased.

Limits of length.

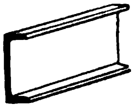
The smaller sections can generally be purchased up to 25 ft. in length without extra charge, and the larger sections up to 20 ft. If these dimensions be exceeded an extra price is incurred, somewhat in the same ratio as for T bars. But with joists, as with other rolled steel, exceptions are made to the rule when the transaction is in other respects favourable to the manufacturer; and sometimes, in such cases, lengths varying from 20 to 40 ft. are supplied without extra charge.

Ready-made joists.

Rolled beams are kept in store by iron and steel merchants in most large towns, so that builders can purchase them as wanted, but, as already stated, in such cases the expense of cutting to length has often to be incurred, which, together with the value of the piece cut off, brings the retail price generally £1 to £3 above the current wholesale price at which such joists can be bought at the rolling-mills.

Cutting to length.

The ordinary practice is to cut the ends of the joists hot as they leave the rolls, and a length which is within 1 in. of the specified dimensions is considered sufficiently accurate. If cut at the rolling-mill to exact lengths cold, an additional cost of from 3*s*. to 10*s*. per ton is incurred.



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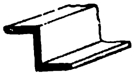

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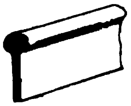

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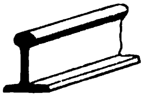


106.

Channel ⊔ bars bear somewhat the same relation to **I** bars as a T does to an L section, and although extremely useful in many cases, their one-sided shape renders them less easy to bend and less convenient for connections than the double T. The smaller and narrower sections are the cheapest, and in this respect, and in the rules by which extras are charged, they may be classed with ⌶ joists, as also in regard to the fact that they are largely made in Belgium, France and Germany. The prices are generally about £1 per ton higher than the price of joists.

L bars and bulb beams are used principally by shipbuilders, and cost about the same as T bars. Hoop steel is made of many qualities, the cheapest being used by builders for bonding brickwork together; a better quality is made for hooping casks, and the best for enclosing bales packed tightly by hydraulic pressure. Hoop steel of ordinary sizes and quality costs about £3 per ton above the price current for small steel beams. Steel hoops have superseded iron hoops for baling purposes or wherever strength is of importance.

Steel not easily distinguished from iron.

This limits the use of steel.

Steel when manufactured into articles of utility cannot be easily distinguished from iron, and the want of some ready mode of satisfying themselves that proper steel has been employed, is one of the causes which at first disinclined engineers from allowing its use. Some authoritative brand or hall-mark seems needed to verify the origin of each separate piece, for the testing a portion of every piece is troublesome and expensive. This verification of quality is more important than in the case of iron, where the inferiority of any particular piece would probably be, at most, 10 per cent.; while, if iron or bad steel be substituted for the prescribed steel, the difference might be 50 per cent.

Cast steel improved by hammering and rolling.

Steel castings.

Compressed steel.

Steel owes much of its homogeneity and close grain to the treatment it receives by hammering or rolling after it has been cast into an ingot. It is for want of such after-treatment that steel castings do not offer so great a tenacity and ductility as wrought steel. Molten steel, after being cast, chills more quickly than iron; the process of casting is not so easy; there is more risk of unsoundness; and for these reasons steel cast into irregular shapes, unless it be afterwards compressed, hammered or rolled, offers a strength inferior to that of simple shaped rolled steel bars. Whitworth's process of compressing steel castings while in a semi-molten condition was introduced to meet these objections, and so far as it has been applied—chiefly (up to 1898) for military purposes, such as guns and torpedo-cases--

Large castings.

Malleable cast-iron.

Advantages of steel castings.

Tensile strength.

See page 540. CAST IRON.

it has been proved very successful. The application of steel to general purposes, such as the parts of large steam-engines and machinery, depends on whether it can be produced of good quality in large masses without forging, and though this is accomplished by a limited number of makers, it is not so easy to obtain sound steel castings as ordinary iron castings. It is largely owing to this difficulty, that malleable cast iron is so extensively used. Made from high quality (generally hæmatite) pig iron, such iron castings are then, by a peculiar process of annealing, partly decarbonised and rendered so tough as to withstand bending or percussion without fracture. But steel castings, when sound, offer considerable advantages over iron castings, where great strength and reduction in weight are required; they are tougher, more elastic, and offer a greater resistance to wear and abrasion, and they often take the place of wrought iron for irregular shapes, where the cost of forging or smithing would be great. Steel castings compare most favourably with iron castings under tensile strains, as they have a tenacity three times or more than that of cast iron, or over 30 tons per square inch. And as steel has also a much greater resistance to abrasion than iron, toothed wheels are for this reason often made of steel.

Prices of crucible steel for tools.

Such articles as turning-tools, screwing-taps, chisels, files, saws, are usually made from high-carbon crucible cast steel, which ranges in price from £30 to £60 per ton; but some special kinds of tool steel cost more than £100 per ton. The higher grades of crucible steel are converted from the best brands of Swedish wrought iron, which vary in price from £12 to £30 per ton; so that the quality of tool steel may be infinitely varied, according to the mixture of high or low priced iron.

Various shapes of tool steel.

Various tempers.

Good steel saves expense.

MACHINE-TOOLS, *See page* 768.

Tool cast-steel is made in bars of various shapes and sizes, such as square for turning, slotting and planing tools; round, for taps rimers, drills, milling-tools, dies; flat, for turning and slotting-tools and shear-blades; round-edge, for chisels and riveting-snaps; octagon, for chisels and snaps. Various tempers are required for these different purposes, and the maker should always be informed of the particular purpose for which the steel is to be used. For want of such knowledge, steel, though of good quality, is often not adapted for the purpose in view. It is false economy to use anything but cast steel of good quality for tools working upon metal, as the higher cost of good steel is more than repaid by its greater durability, and the great saving of time in re-sharpening. But prices more than proportioned to their value are charged for some of the best known brands of steel. Shear-steel is generally used for welding purposes, and varies in price from £30 to £60 per ton, the higher qualities being used for machine cutting-tools, composed of steel and iron welded together.

Shear-steel for welding.

In regard to all the kinds of steel classified in the preceding pages, continual progress has been made in the methods of manufacture, first in regard to quality, to arrive at the exact mixtures and alloys suitable for particular purposes, and secondly by the use of gas fuèl and machine processes to reduce the cost. While however, in the case of rails, plates and bars, where large quantities can be made with a regular sequence of operations, these economies are feasible, many of the special steels required in moderate quantities demand an elaboration and watchfulness which confine the possible savings to a narrow range.

[*See also* COAL AND IRON MINING *in* CHAPTER XV.]

CHAPTER XXI.

THE PURCHASE OF STEAM-ENGINES. GAS-ENGINES. OIL-ENGINES. HOT-AIR ENGINES. WATER-ENGINES. ELECTRIC MOTORS.

Other kinds of heat motors.
See pages 602–8.

Water-engines.
See page 609; *also* TRANSMISSION OF POWER, *page* 494.

THE effective force generated by the combustion of fuel, even in the best kind of steam-engine, is still far below the theoretical heat-force of the fuel, and as, moreover, there are certain inconveniences which attend the use of the steam-engine, constant attempts are made to discover other methods of transmuting heat into mechanical force, either by improvements in the engine itself, or by means which avoid the use of steam altogether. Gas-engines, petroleum-engines and hot-air engines have each their place; while outside any category of heat motors, water-engines are available, not only as original motors where there are natural sources of water, but also for giving effect to the gravity-force of water which has been pumped up by a steam-engine or other prime mover at a distance. Electric engines are available as secondary motors for utilising the power of a steam-engine or other primary motor at a distance. It is not intended here to describe or suggest any new method, but only to draw attention to the circumstances by which the value of steam-engines, and the substitutes above mentioned, is determined and on which a choice depends.

Steam-engines valued by their power.

The primary measure of value in a steam-engine is its power; but this, as it is derived from the fuel consumed in the furnace of the boiler, depends in the first place on the size or capacity of the boiler and furnace. The gross heat-force being thus arrived at, the net effective value depends on the waste or loss between the heat-force contained in the fuel and the mechanical force given out; this waste or loss depending on the design and construction of the machine. Such a simple measure is not, however, sufficient; for it is the suitability of an engine to the special wants of a purchaser which determines its value in any particular case; and the power which one engine will give as compared with another is only one out of many points which have to be considered.

Other conditions of value.

Variety in kind of engine perplexing.

The diversity of purpose to which the steam-engine is applied has been met by a corresponding variety in the kinds of engines; and this variety, though advantageous in the wide choice it affords, is often a source of perplexity to the purchaser. Inventors and manufacturers draw attention to the points of excellence in their machine, to the conveniences it affords and the difficulties it overcomes; and till another set of conveniences and difficulties is considered, it might be thought that one particular engine must be the best for all cases. Precedent should not be followed, nor success already achieved be taken as a guide, unless the conditions of use are sufficiently alike. Some of the following points have generally to be considered, besides the primary question of the power required.

Precedent should not always be followed.

Points to be considered.

Purpose.

1. The *Purpose* for which the engine is required; this determining many points such as speed, equable or continuous running, the need for reversing apparatus, facility of adjustment and other conditions, for which some kinds of engines are better suited than others.

2. The *Space* to be occupied by the engine and boiler; for if there be limitations in this respect, the design of the engine may be modified accordingly. If floor space be limited, some kind of vertical engine and boiler may have to be adopted, which may be less solid and durable and more expensive than a horizontal engine. The use of high-pressure steam allows economy of space. This is absolutely necessary in a marine engine or locomotive, and sometimes also in fixed land engines.

Exigencies of space.

Weight of engine.

3. The *Weight* may be a point of consequence, if the engine and boiler have to stand upon an upper floor, or on a weak foundation. If weight for transport is an important consideration, not only the total weight, but that of the separate pieces must be considered, and

the larger pieces, such as boiler, bed-plate and fly-wheel, may be made to subdivide for carriage.

Portability.
See pages 591–3.

4. If frequent *Carriage* from place to place be probable, a portable engine may be best, but if only occasional moving is anticipated, a fixed engine with parts conveniently divisible may be preferred.

Facility in setting to work.
See pages 590 *and* 450.

5. Facility for *Fixing* and setting to work is sometimes an important point, and it may be expedient to make the machine so complete and self-contained as to require little preparatory labour in buildings and foundations, and no preliminary adjustment of the mechanism as a condition of proper working.

Quickness in starting.
See page 636.

6. A minimum *Time* for starting may render necessary a peculiar kind of boiler and other arrangements: the steam-engines for cranes, winches and fire-engines being examples.

Economy in fuel.
See pages 572 *and* 620.

7. Economy in *Fuel* and suitability for particular kinds of fuel are conditions which often modify the design; but the extent to which the engineer can meet these conditions is often limited by other of the points mentioned.

Cheapress of price.

Cost of accessories must be included.
See page 590.

8. Economy in first *Cost* often overrides all the other considerations, for, though it is generally cheaper to have only what is best and most suitable, even a rudely-constructed engine, or one consuming much fuel (if the only one which can be afforded) may still prove of great advantage when compared with other sources of power available as an alternative. Of course, in measuring the cost, or in comparing one kind of engine with another, the expenses of foundations, buildings and other accessories need as much consideration as the machine itself.

Horse-power.

Different terms elucidated.

Watt's rule.

Foot-pounds.

In most of the technical questions concerning steam-engines, and in their commercial valuation, the "*Horse-power*" is by common usage adopted as the unit of measurement; but as the term is qualified by the prefix "Nominal," "Indicated," "Effective," "Real," "Brake," the relation which these phrases bear to each other needs explanation. Watt, in introducing his new steam-engines one hundred years ago, required a convenient and easily understood measure of power, by which the value of his engines could be stated; and having by experiment ascertained that a very strong horse could lift 33,000 lbs. one foot high in one minute, he adopted this as his standard, for, although 25,000 lbs. would more correctly represent the usual power of a horse, Watt preferred the higher figure, as demonstrating with greater effect the value of the machine he had invented. The lifting one pound one foot high has, under the name foot-pound, been adopted as a unit of measurement for the power not only of steam-engines, but of all kinds of mechanical forces. Watt made the parts of his engines of such dimensions and capacity as would, with the steam pressure at his command, produce the required power; and the sizes of the principal parts—notably the diameter of the steam cylinder—thus determined, became established, though informally and with certain modifications, as standards among engine-makers. Watt's measure of horse-power has been adopted in most foreign countries. In France, where metrical measures are in force, 75 kilogrammètres (kilos lifted one mètre) per second are taken as one horse-power, and this equals 0·986 of the British horse-power. In Germany the horse-power slightly exceeds the British standard; in Russia it is exactly the same. Watt based his calculation of horse-power upon an assumed steam pressure (in addition to the vacuum-force he obtained) of 7 lbs. per square inch, and a piston speed of 160 feet per minute; an increased piston speed being adopted as the stroke was made longer than 2 ft., so that with a stroke of 8 ft. the speed was calculated at about 260 ft. per minute. The same rule would apply for the earlier non-condensing, or as they were called, high-pressure engines, but with a direct steam pressure of 21 lbs. But with the use of higher pressure steam, of greater velocities, and of numerous improved methods, engines made now of the same dimensions as formerly give out much greater power, and hence the difference—2 to 1, 3 to 1, or even 6 to 1, as the case may be—between the nominal and real power of a steam-engine made now of the old dimensions. Watt's dimensions have not been strictly adhered to, and though no absolute rules have been established, the competition of makers has led to conventional standards of size in different districts. Among the various modifications of Watt's rule, that which allows a non-condensing engine about 10 circular inches of piston area for each nominal horse-power is one of the most simple and usual. Thus, a cylinder 8 in. diameter, having an area of 64 circular inches, will be provided for a 6 horse-power engine, a 10-in. cylinder for a 10 horse-power engine, and a 12-in. cylinder for a 14 horse-power engine. It is evident that an arbitrary rule of this kind may be applied with widely different results, according to the length of stroke, pressure of steam, speed and other circumstances, and the competition of manufacturers has led them in some cases to adopt rules for themselves which are misleading. So long, however, as there was an understanding acted

Standard rule adopted.

Metrical equivalent.

Foreign H.P.

Steam pressure assumed by Watt.

No longer used.

Power increased by high pressure.

Power according to piston area.

Affords variable results.

Nominal H.P. implies a certain real power.

on by makers of engines and known to purchasers, of what dimensions were really implied by a certain specified nominal horse-power, the term, though arbitrary and conventional, could not be called useless; and until engine-makers in different countries agreed upon some better method of denominating their machines, the old term was used; and if it were attempted instead, to state the real power, then as this depends upon the pressure and velocity—incidents which may, in an engine of given dimensions, be varied at will within very wide limits—such a statement, unless accompanied by the exact conditions upon which it is calculated, might not convey to the purchaser of a steam-engine so good an idea of the machine in question as would the nominal horse-power, which implies certain conventional or prescribed dimensions. For the same reason, there is no fixed proportion between nominal and real horse-power. Amongst engineers the nominal horse-power is seldom referred to; its use is confined mainly to the enumeration of portable and small engines in catalogues, and the real power, as determined by the dimensions, pressure and speed, is alone considered.

Difficulties in stating real power.

Engineers ignore nominal H.P.

The indicator.

By means of an instrument called the "indicator," the pressure per inch upon the piston, with the variations of pressure at each portion of the stroke, are exactly measured and recorded; and the mean of such varying pressure, multiplied by the number of inches of piston surface, gives the total force exerted upon the piston. This total force, when again multiplied by the number of feet travelled by the piston per minute, produces the sum of foot-pounds of work done, which, divided by 33,000, expresses the "indicated horse-power" according to Watt's standard. But from the gross power thus arrived at must be deducted—if the net or effective or real power is to be ascertained—the power consumed in overcoming the friction of the engine itself; and in the majority of cases—in each according to the skill of the maker and other conditions—the proportion to be deducted is somewhat between one-fourth and one-eighth of the gross power. In a well-made engine the percentage should not exceed 12 per cent. The effective or dynamic power can, if desired, be exactly measured in all engines of moderate size, either by a dynamometer, or by a friction brake, as has often been done in the competitive trials of portable and other engines, and by some makers the brake power is demonstrated with each engine as sold.

Shows pressure and speed.

Indicated H.P.

Real or effective H.P.

Dynamic force.

Brake H.P.

As the immediate purpose of a steam-engine is to transmute into effective mechanical energy the heat-force of fuel through the medium of water evaporated into steam, the efficiency of the engine in regard to design, manufacture and working may be measured by the amount of force given forth for each pound weight of water consumed in the boiler. According to the kind and efficiency of the engine in this respect, from 0·017 to 0·066 indicated H.P. will be given out for each pound of water fed into the boiler, the higher amount being that of the best engines under the best conditions. Or, to reverse the statements, from 15 to 60 lbs. of water have to be evaporated for each H.P., the worst cases occurring where the steam has to be conveyed considerable distances, in ill-covered pipes, to an engine working at irregular intervals. This very wide range of difference illustrates the economy or wastefulness of different engines. Thus, a well-made, well-managed, non-condensing engine will consume only 24 lbs. of water; an ill-made and badly managed engine as much as 60 lbs. A compound non-condensing engine will consume from 18 to 45 lbs., while a condensing engine will range from 15 to 25 lbs. And, as already stated, the real or effective power is from 75 to 88 per cent. of the gross power.

Efficiency measured by water evaporated.

Wide range of difference.

See page 483.

Water consumption.

The economy of working obviously depends also on the amount of fuel consumed to evaporate each pound of water. As the temperature of water when fed into a boiler varies in different cases, and as the heat at which the evaporation takes place also varies according to the pressure of steam, it is usual, in order to arrive at a common standard for comparing the efficiency of different boilers, to reduce the calculation in each case so as to measure the evaporation at and from 212° (Fahr.), that is, to an assumption that the water is fed into the boiler at 212° and the evaporation takes place at 212°, so that no fuel has been expended in heating the water to boiling-point or in raising it, but only in evaporation. On this basis from 8 to 11½ lbs. of water is the range of evaporation per lb. of coal, according to the quality of the coal and the efficiency of the boiler, this being about 18 per cent. more than the results would be under such average actual circumstances as feed water at 60° (when not heated) and evaporation at 300°. In the latter case from 6½ to 10 lbs. of water per lb. of coal would be the range of evaporate power.

Economy in work depends on fuel consumed.

The relation which the cost of fuel bears to the purchase-money of an engine, and the extent to which economy may be practised, may be illustrated by an example. Let it be assumed that an ordinary non-condensing engine of 20 nominal horse-power will

Example of fuel consumption.

In non-condensing engines.

Saving effected by using steam expansively.

Further saving by condensing.
See page 582.

Minimum consumption.

See COAL, *page* 532.

See GAS, *page* 605.

See GAS-ENGINES, *page* 602.

cost, including boiler, about £500; and let it also be assumed that such an engine will be worked at a pressure and speed which will give out 50 indicated horse-power. With coal of ordinary quality the consumption will probably be some quantity between 5 and 10 lbs. per indicated horse-power per hour, the lower amount requiring a well-designed engine and good stoking, and the higher, though generally implying an unnecessary waste, being even less than takes place in many engines. Assuming that the engine is working 60 hours per week, or 3000 hours per annum, the yearly consumption of fuel will be from 335 to 670 tons, which, at the value of £1 per ton, shows a difference, and therefore allows a margin for saving, of £335 per annum. If high-pressure steam be used expansively, and the feed water heated with the exhaust-steam, the consumption may be reduced to lower limits, say from 4 to 7 lbs., according to the skill in stoking and other circumstances. But even the lower of the two rates involves a very unnecessary consumption of fuel. An ordinary condensing engine, to produce the same indicated horse-power, would probably cost about £600, and would consume only from 3 to 5 lbs. of coal per indicated horse-power per hour; and by the skilful use of compound engines, and well-arranged boilers, the consumption can be kept down to 2 lbs., and even 1½ lb. has been reached for a short time under specially favourable circumstances. As, however, even 1½ lb. is far in excess of what in theory will generate steam equal to 1 horse-power, it would be presumptuous to affirm that further economies are impossible in the future. In some cases it is probable that the saving will be best effected by using gaseous fuel, that is to say, by first making gas from the coal and then consuming it in a gas engine, so avoiding the intermediary of a steam boiler.

Cheap coal does not justify waste.

It is a mistake, however to suppose that where coal is cheap an excessive consumption may be disregarded, for not only has the cost of the coal to be considered, but the additional furnace capacity for burning the coal, the wear and tear of the boilers, the extra labour in stoking and the removal of the cinders. These expenses will together almost always exceed the interest on the capital apparently saved by buying cheap engines which consume much fuel.

Economy in fuel, how obtainable.

As just stated, economy in fuel depends upon the proper construction of both engine and boiler, and can only be maintained by skilful management, these essential conditions requiring that—

Waste of fuel in furnace avoided.

(*a*) The fuel shall all be consumed in the furnace without being wasted either in the form of combustible cinders, smoke, or vapours. To this end it is necessary that the boilers shall be of a proper kind, and properly set.

Escape of heat prevented.

See page 576.

(*b*) As much as possible of the heat generated in the furnace shall be transferred to the water in the boiler, and the minimum amount escape either into the stoke-hole or up the chimney; this efficiency requiring a large heating surface and good stoking.

Loss by radiation avoided.

(*c*) The heat in the boiler shall not be wasted by radiation from the boiler or from the pipes which conduct the steam to the engine; and to ensure this, the boiler, steam-pipes, and cylinder must be protected from loss by radiation by some non-conductor of heat.

Steam all to be used in engine.

(*d*) The steam which reaches the engine shall be utilised there to the utmost, and therefore none of the steam in the engine shall be allowed to escape till as much as possible of its direct and expansive force has been utilised. Compound and triple-expansion engines are designed to effect this. The feed water should be heated by the waste heat in the boiler flues or by the exhaust steam.

Friction of engine kept low.

(*e*) The force necessary to overcome the friction of the engine itself, and which is lost from the effective power, shall be kept as low as possible; and therefore that the engine shall be so designed, and so well fitted as to require the minimum of power to work it.

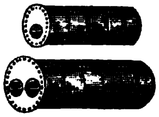
Boiler and engine considered separately.

While, however, economy thus depends both upon the boiler by which the steam is produced and upon the engine which uses it, the two are, as has been seen, entirely distinct, and need separate consideration.

Egg-ended boiler.

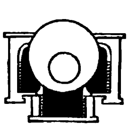
107.

The earliest *Boilers*, though made of various forms—egg-ended, wagon-shaped, circular with domed tops—were without internal flues of any kind; the furnace below the boiler and the flues around it being constructed in brickwork. Although much skill was sometimes shown in the arrangement of the flues, a large proportion of the fuel was wasted either in the form of unburnt coal and cinders or in the smoke and heated vapour allowed to escape up the chimney, or as heat given out from the surface of the boiler and its surrounding brickwork. The water could not be heated quickly, and boilers of large size were necessary to produce sufficient steam. Boilers of this kind are very seldom made now, though they are occasionally to be found at collieries and places where there is much cheap fuel, or where there is refuse fuel, a riddance from which is desired, or where the waste heat from coke-ovens or furnaces can be utilised. The wagon-shaped boiler, which contains one tube or flue, was an advance on the previous kind; but the great advantages as regards strength which a circular shape allows, caused the wagon shape also to be superseded. The Cornish boiler and the Lancashire boiler were a marked improvement upon any of the previous kinds. They are of cylindrical form, generally of some diameter between 4 ft. 6 in. and 8 ft., and of some length between 8 ft. and 30 ft. They contain one or two internal tubes or flues, boilers not exceeding 6 ft. diameter generally having one, and those more than 6 ft. diameter two, of such tubes; those with one tube being known as Cornish, and those with two tubes as Lancashire boilers. The tubes are of some diameter generally approximating to one-half of the diameter of the boiler when there is one tube, and to one-third when there are two tubes. In each tube is placed a furnace, and the flames and heated vapours having passed along the tube are, in the majority of cases, then taken under and along the outside of the boiler in brick flues, and thence to the chimney. The advantages afforded in the heating of the water by thus having the furnace and the hottest of the vapours in the interior of the boiler are obvious; and boilers of smaller size than those without internal flues will produce as much steam in a given time.

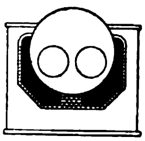


108.

Cornish and Lancashire boilers.



109.



110.

Multitubular boilers.

See page 599.

Multitubular boilers are either vertical or horizontal, and almost always cylindrical, even for marine engines, where they were formerly of such shape (generally rectangular) as best suited the exigencies of space in a steamship. But the advantages of a circular form led to its adoption in marine boilers to resist high-pressure steam. In multitubular boilers there is the same principle of internal flues as in a Cornish or Lancashire boiler, but instead of one or two tubes there are numerous tubes of small diameter, generally from 2 to 3½ in. diameter, through which the gases pass to the chimney. The heated surface which is presented to the water, by thus piercing it with a multitude of fiery tubes, is in the aggregate very great, and steam can be produced rapidly; a great reduction in the size of the boiler is allowed; and it can be made complete or "self-contained" without the necessity for any brickwork flues or setting. If the adoption of this method of constructing boilers were not limited by certain opposing considerations, all other kinds would be soon abandoned. The question is an important one, on which there are

Have great heating surfaces, and produce steam rapidly.

Are self-contained, and need no brickwork.

Advantages.

Locomotive boilers.
See page 698.

The steam-blast.

Marine boilers.

Have larger and shorter tubes.

constantly diverse opinions. The multitubular boiler was first designed for locomotives, as, in the small space there available, one or two internal tubes of large diameter were totally inadequate. The rapidity with which water can be heated and steam generated in a multitubular boiler (so that from a boiler of limited size a large supply of steam can be kept up) at once ensured its adoption. In a locomotive, although economy in fuel is desirable, as in other engines, the production of sufficient steam in a boiler whose size is necessarily limited, is the primary consideration, and the one which renders the multitubular system absolutely essential. But even the numerous tubes would be insufficient to produce steam quickly enough for the purposes of a locomotive, were it not for the happy addition of the steam-blast. The exhaust-steam from the engine cylinders is discharged in such a manner as to intensify the draught through the tubes, the vapours from which are taken with the steam in one rushing blast up the chimney. In a marine engine, although there is not the absolute impossibility, as in a locomotive, of having outer flues of brickwork, it may be considered practically impossible. As, however, in marine engines, there is seldom a blast to stimulate the draught and keep the tubes free from soot, and as the tubes cannot be cleaned so often as in a land boiler, the tubes are made larger and shorter, a diameter of about 3½ in. being usual, while in locomotive or portable engines the tubes range from 2 in. to 2½ in. Combustion is, however, encouraged in some marine boilers by a forced draught, air being forced into the stoke-room, or into the furnaces, by revolving fans.

Boilers of portable engines.
See page 593.

Drawbacks to multitubular boilers.

Less durable than Cornish boilers.

In a portable engine, the importance of having a boiler sufficiently small, and the impossibility of having outside flues of brickwork, render the multitubular boilers almost as necessary as in a locomotive. In these three important kinds of engines, therefore—the Locomotive, the Marine, and the Portable—there can be no difference of opinion as to the propriety of using multitubular boilers. But in regard to stationary engines, opinions are divided. Multitubular boilers as usually made in Great Britain, of the locomotive type, are self-contained, need have no outside setting, and though tubes have periodically to be replaced, such boilers hardly ever explode. On the other hand they cost more than Cornish boilers, require repairs more frequently, are less accessible for repairs and cleaning, and do not last so long. The furnace, firebox and tubes, and their connecting parts, have to endure fiercer and more concentrated heat than the simpler parts of a larger

Other inconveniences.

How neutralised.

Spare boilers.

See page 202.

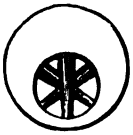
Cornish boilers best for fixed engines.

Relative cost of boilers.

Cornish or Lancashire boiler. The inconvenience and loss which are occasioned by the bursting of a tube, or by any other mishap which involves the temporary stoppage of the engine, together with the trouble and expense of replacing a worn-out boiler by a new one, disincline many users of steam-engines from multitubular boilers, and lead them to prefer the Cornish type of boiler. These inconveniences can be, and often are, largely neutralised by having one or more spare boilers ready for use during the repair or replacement of a defective one; and the capital sunk in such extra boilers must be considered as an investment, for which the compensations obtained are a sufficient return. In stationary engines, however, there is not the same limited space as in the engines just now alluded to; and it is in such cases, where there is ample room for external brick flues, that Cornish boilers appear to the best advantage, and, when well arranged, consume less fuel than those "self-contained" multitubular boilers without external flues. But there is a growing tendency towards the use of high-pressure steam and quick-speed engines, and it is sometimes difficult in a Cornish boiler, unless it be made of excessive size, to maintain a sufficient supply of steam. Moreover, the small size of multitubular boilers not only renders them stronger than the larger Cornish boilers, but they are of less weight, and occupy less space. When a Cornish boiler for a 20 horse-power engine would cost, complete with fittings, £180, a multitubular boiler would probably cost about £250, but the latter may, if desired, be arranged with little or no brickwork.

Both kinds combined.

Such opposing conditions have suggested many expedients, which have generally taken the shape of some compromise between the two kinds of boilers. In some Cornish or Lancashire boilers, vertical or diagonal tubes are inserted across and through the ordinary tubes, by which plan the effective heating surface is much increased, a beneficial circulation of the water promoted, a more rapid generation of steam caused, and the main tubes are strengthened against collapse. In other cases a boiler of a hybrid kind is constructed, with the furnace and parts adjacent of the Cornish form, and the further part multitubular. In both these cases the parts are more accessible than in an ordinary multitubular boiler; and as the heat in the further end of a boiler flue is only a fraction of that in the furnace, the small tubes are not severely tried; and there is the same advantage as in an ordinary Cornish boiler, of having external flues of brickwork. If the latter are adopted, the heated vapours,



111.

Cross tubes.

Hybrid boilers.

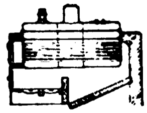
after leaving the internal tubes, can be effectively conveyed round the outside of the boiler, and the minimum allowed to pass up the chimney in waste. With a properly proportioned grate-surface, and by careful stoking, the consumption of fuel in such boilers can be kept as low as in any known kind of boiler. Cross tubes, as above described, are now generally inserted in the furnaces of small self-contained vertical boilers used for steam-cranes, winches, and similar purposes, as it is found that numerous smaller tubes would, in so confined a space, be liable to be choked up and to burn away. In the small boilers used for these purposes, it is impossible to prevent the escape through the chimney of heated vapour which in larger boilers might be utilised; but as no other kind of boiler is practicable, the great convenience and saving which such engines afford, as compared with manual force, justify the consumption of fuel which takes place. Thus, while in a small cross-tube boiler the heat in the chimney may exceed 700°, that in the chimney of Cornish or Lancashire boilers can be kept as low as 400°, for if the temperature in the chimney exceed 400°, it can be reduced by interposing a feed-water heater to absorb and utilise some of the heat.

Boilers for small engines.
See CRANKS, *page* 799.

Consume much fuel.

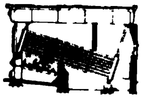
Lancashire boilers not used in United States.

In the United States, boilers of the Cornish or Lancashire type are seldom used and, for fixed engines, either a multitubular boiler set in brickwork, or a water-tube boiler is preferred. In the first of these the furnace is constructed in brickwork below the boiler, the outer plates of which receive the fiercest of the fire. The flames and heated vapours having passed forward, return the whole length of the boiler through the tubes, and then, by side flues in the brickwork, to the chimney.



112.
American boilers.

Water-tube boilers are composed of groups of tubes of from 3 in. to 6 in. diameter, so arranged in a brick setting that the flames and vapours pass through and between the groups in the opposite direction to that in which the water circulates in the tubes. The horizontal trunk above the tubes forms a water and steam space. These boilers, whose component parts are small and simple, are more easily made than those of plates riveted together; the tubes, being of small diameter, are strong against the steam pressure, and all the parts of the boiler being of moderate size and weight, can be easily carried and put together *in situ*. These advantages were great in a country having long distances for transport, and in cities where the making and setting of large Lancashire boilers would be difficult. The fact that



113.
Water tube boilers.

Convenient for carriage.

the earlier boilers of this type were mainly composed of cast iron, led European engineers to distrust them, but since the tubes have been made of welded or drawn steel, and the tube-boxes or "headers" in which the tubes are assembled are also of steel pressed into shape, the several advantages afforded are more widely appreciated. The boilers involve the minimum of risk, as the quantity of stored-up steam is smaller than in other boilers; a failure of any one tube is limited in its effects; spare tubes can be kept in stock; and the boilers can be easily repaired.

Improvements in water-tube boilers.

Belleville boilers.

Water-tube boilers of the "Belleville" type were first used in the French navy, and the same principle having in England been tried successfully in steam launches, was, about the year 1895, applied in war-ships of the largest size. Steam can be raised very rapidly in these boilers, and the small parts of which they are composed can be easily repaired or replaced at sea. But while they have been used almost exclusively for marine engines, they may be convenient in land engines also where it is desired to obtain steam-power in the smallest space.

For marine engines.

Opposing conditions in choice of boilers.

So long as engineers or users of steam-power are met by opposing conditions—as for instance, on the one hand, by a limited space or the need for a self-contained boiler independent of all brickwork, or for one which will generate steam very quickly: and on the other hand, by the inconvenience of tubes or connecting parts which may require frequent cleansing, repairs, or renewals—there will remain for consideration how best these conditions can be reconciled and the best result attained. The conflicting merits and demerits of different kinds of boilers can only be weighed, and a proper choice arrived at, on the basis of the circumstances enumerated on pages 567–68. Whatever boiler may be adopted, the amount of fuel consumed will of course much depend upon its quality, on the proper air-spacing of the fire-bars, and on the efficiency of the stoking. Conversely, the kind of fuel which will be most effective depends upon the form of the boiler, the shape and size of the furnace, and on the draught. Some kinds of coal demand a great draught; there are others in which combustion must be checked; and if certain kinds of fuel are more easily obtained than others, it is very important that the boiler should be constructed accordingly.

Choice depends on varying circumstances.

Different kinds of coal.

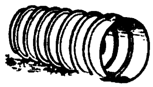
See COAL, *page* 527.

Steel boilers.

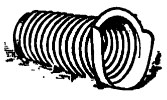
See also page 560.

The introduction of Bessemer and other modern kinds of steel led to the use of much higher pressure steam than formerly, for though the advantages of using high-pressure steam expansively were beginning to be recognised before steel was available, iron boilers with plates of moderate thickness were not strong enough, except in boilers of small diameter, to give a sufficient margin of safety, and, if made thicker, the plates were not only more difficult to bend and rivet, but impeded greatly the transfer of the heat from the furnace to the water, and the plates were liable to become unduly heated. But by using mild steel, having a tensile strength of about 27 tons per square inch, instead of iron, where only 20 tons can be safely depended on, a corresponding increase in the working pressure is allowed without increasing the thickness, and steel is universally used in boilers of large diameter working at pressures above 100 lbs. But while the outer shells of circular steel boilers have a high resistance to the tensile strains they have to bear, the internal flues, which have to endure an outer or crushing force, are not, if of a plain cylindrical form, sufficiently strong to resist collapse. This is especially the case in marine boilers, and to meet these cases the flues are made with corrugations, sometimes spirally arranged and sometimes at right angles to the axis, these corrugations, though inconvenient in some respects, affording the necessary stiffness.

Advantages of steel.



114.



115.

Corrugated flues.

It is usual in the purchase of boilers to have them tested before leaving the manufactory—a test with water to double the intended working pressure, and a subsequent test with steam to the maximum working pressure, being usual. But tests of this kind, though proving the absence of gross faults in workmanship, and of flaws in the iron or steel, do not alone prove the sufficiency of the boiler for long service. Boilers have to endure not only the pressure of the steam, but severe strains from the alternate expansion and contraction of the iron or steel when hot and cold, and also the action of the fire upon the plates in and about the furnace. As it is important to have a sufficient margin of safety against these contingencies, it is usual to stipulate for a certain thickness and quality of iron or steel; and makers in stating their prices may be called upon to specify these points. In certain parts of the boiler the quality of the material is sufficiently proved by its enduring the flanging, bending, and other treatment during manufacture, and if of iron, a superior quality made from refined cold-blast iron is generally used for parts exposed to the fire.

Boilers tested.

Thickness and quality of iron specified.

See page 549.

Classification of steam-engines.

Stationary Steam-engines may be divided into three kinds, and placed in the following order: non-condensing-engines, condensing-engines, compound engines. For the first of these the ordinary

High-pressure or non-condensing engines. name was formerly "high-pressure" engine, because, since its power was derived directly from the steam instead of from the vacuum produced in a condenser, higher pressure was employed than in the latter case. But now that high-pressure steam is used in condensing engines, the term is not sufficiently distinctive and often misleads. **Are simplest and cheapest.** *See page 582.* *See page 699.* The vast majority of engines now made are non-condensing, the additional apparatus required in a condensing-engine occupying space, while it renders the machine more complicated and expensive. In a locomotive, the limited space would alone render a condenser impossible, and the same objection applies with almost equal force in portable engines of all kinds. In a marine engine, different conditions determine a choice, for—unlike the locomotive, which need only carry coal for a few hours' consumption—a large supply has to be **Marine engines always condensing.** carried, the space occupied by which is very valuable. The economy in coal, and therefore in the stowage space for coal, which condensing engines allow, far exceeds the value of the extra space which a condensing apparatus occupies, and as also water is abundant for surface condensation, condensing engines are used in all steamers, except in **Exceptions.** small boats for river or harbour service, which can take in fresh coal as often as a locomotive.

Low-pressure steam. Non-condensing-engines were, up to about the year 1850, generally worked at a pressure of from 20 to 40 lbs. per square inch; and the steam, after being admitted to the cylinder during nearly the whole of **Wasteful.** the stroke, was discharged into the atmosphere at a considerable and therefore wasteful pressure. Boilers and engines had to be made of large size to produce a given power, and the consumption of fuel was **High pressure adopted.** excessive. It was found, however, that boilers could as easily be made strong enough for high as for low pressure, and the practice of using steam expansively became general. It is a matter of the simplest **Expansion of steam advantageous.** demonstration, that steam worked expansively, that is to say, high-pressure steam admitted to a cylinder for only a portion of the stroke —one-third, one-fourth, or one-sixth, as occasion may require—and then, the supply from the boiler being shut off, allowed to expand into the increasing space left by the advancing piston, will, by such a method, produce a given power with far greater economy than is possible with the old system. Since the expansive use of steam has **Usual high pressure.** become adopted, a pressure of 80 to 100 lbs. is commonly used in stationary engines; and the advantages obtained are so considerable that greater pressures have become general in the best types of engine. **Saves space.** Moreover, space is saved by obtaining the best effect from an engine of given size, and the additional cost for making the various parts strong enough for the power given, is small compared with the advantages gained.

Usual pressure in locomotives. *See page* 699.

Locomotives, in which great power has to be concentrated into small space, are worked at from 120 to 170 lbs. per inch; but this requires a forcing of the combustion, which does not tend to economy in fuel, and is not expedient therefore for ordinary fixed engines. The use now of higher pressure steam than formerly, enhances the value of those precautions which are necessary to prevent waste by premature condensation. Steam as it leaves the boiler always contains more or less water, as shown in extreme cases by "priming"; and however much the pipes and other parts may be enveloped in material which is a non-conductor of heat, condensation takes place which increases the amount of water in the steam, and there is a loss of pressure which implies a corresponding loss of fuel. To counteract this condensation, the principle of superheating was introduced. This consists in increasing the temperature of the steam after it leaves the boiler, so as to transform into steam the globules of water held in suspension, and beyond this, to dry or superheat the steam to a higher temperature than that which corresponds to its elastic force; and this extra store of heat compensates for the loss, which in any case it must undergo, in transmission to the engine; and also tends to prevent the condensation of the steam during the expansion in the cylinder. Various forms of apparatus have been used for superheating steam, but in most of them it is sought to conduct the steam, in its passage from the boiler to the engine, through pipes or vessels heated by the waste vapours from the furnace. It has been found, however, that steam superheated beyond a certain point damages the valves, pistons, packing and other working parts of the engine; and for these reasons the application of this system, even within safe bounds, has been greatly limited. A step in the same direction is the making of engine cylinders with steam-jackets, or, in other words, giving them a double shell, so that when the annular space between the shells is filled with steam, a high temperature inside the cylinder is maintained, thus reducing the partial condensation which the steam inside the cylinder undergoes when brought into contact with a surface of a temperature less than its own. Steam-jacketing is most needed where high-pressure steam is used and cut off early in the stroke, to minimise the reduction in temperature during expansion. Even without steam in the jacket, a double shell is effective in

Priming of boilers.

Superheating.

How effected.

Application of system limited.

Steam-jackets.

Where adopted.

minimising the fall in temperature inside. But notwithstanding all precautions, there is a great loss at this point in the process of transmuting heat force into mechanical energy. The great difference between the steam force generated in the boiler and that utilised in the engine cylinder, as shown by an indicator diagram, mostly arises from loss during expansion.

High-pressure condensing-engine.

More costly.

But saves fuel.

See page 572.

Not suited to small engines or very high pressure.

A certain stage in the path of economy having been reached by using high-pressure steam expansively, and by steam-jacketing the cylinders, the next step forward was to use high-pressure steam in condensing-engines. Although the first cost is greater and more space is required, and more working parts are rendered necessary, the economy in fuel which the use of condensers allows, more than outweighs these drawbacks in the majority of cases. Small engines are not, however, usually so made, and 20 horse-power may be stated as about the point at which condensing engines commence. As, however, the gain (which ranges from 12 lbs. to 14 lbs. per square inch on the piston) afforded by condensation is less in proportion to the total force as the pressure of steam is increased, condensers are seldom applied to land engines working with more than 80 lbs. steam pressure except in compound engines.

The strict analysis to which the operations of a steam-engine have been subjected in all its parts, and the unprofitable consumption of fuel which such analysis discloses, led to the closer appreciation of the conditions of economy and to the consequent introduction of compound-engines. In these the exhaust steam from the cylinder, having first been allowed to expand, is then, instead of being discharged into the atmosphere (or if in a condensing engine into the condenser), transferred at its reduced but still effective pressure into a second cylinder of larger diameter, where it expands still further, so that when it exhausts into the atmosphere or into a condenser its pressure is not more than 1 to 5 lbs. per inch.

Compound-engines.

This method became generally known about 1850, and its adaptation to marine engines took place about fifteen years later. For sea-going steam-ships, where the stowage of the coal as well as its cost is important, compound-engines or triple-expansion engines, where the principle is carried still further by having three instead of two successive expansions, may be said to be now universally adopted. An even further development, by using quadruple expansion, is sometimes adopted, but the saving is slight, and not always deemed sufficient to balance the extra cost and inconvenience of obtaining it.

Triple expansion.

Quadruple.

Engines classified according to shape.

Beam-engines.

Advantages.

Where used.

See pages 202 *&* 617.

Not suitable for high speeds.

As condensing-engines.

Are costly.

Are less used than formerly.

Another classification of steam-engines is according to their shape. The rocking-beam was the form in use for pumping-engines when Watt commenced his career, and it was this form of engine which he adopted, and in which he introduced all his improvements. The ease and smoothness of action in a beam-engine render it perhaps the most enduring of all, and the vertical cylinder, in which the piston wears more equably than in a horizontal engine, is an advantage valued by some engineers. In cases where a steam-engine is required for regular, unchanging, and permanent work, at moderate speed, and especially also where a breakdown would be attended with disaster—all of which conditions are, for instance, met with in the case of a pumping-engine for supplying a town with water, or in the blowing-engine for a blast furnace—many engineers still prefer the beam-engine; but beam-engines are not adapted for the high speeds which, for other purposes, are found advantageous in modern practice. It was formerly the custom in spinning factories, engineering workshops, and similar cases, to transmit the power of the engine from the fly-wheel by belts or gearing, which increased the speed, but it is now considered better to work the engine itself at a higher speed and to continue the main shaft direct into the factory. This practice alone leads often to the substitution of horizontal engines. Beam-engines are generally made with condensing apparatus; they are seldom made smaller than 30 horse-power; they cost from one-fourth to one-half more than horizontal engines; and longer time is required for making them. Beam-engines not only cost more, but they also require more expensive buildings and foundations; and it may be stated, as an almost universal opinion of modern engineers, that beam-engines do not offer advantages sufficient to justify their cost, and they are every year becoming fewer in proportion to other kinds.

Horizontal engines.

See also page 618.

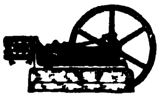
As winding engines.

Ordinary type.

Horizontal engines, of which more are made than of all other kinds put together, are simple and compact; they lie low and steadily on a level foundation easily constructed, and are cheap. They are the kind now most frequently adopted, even for pumping from mines, where beam-engines were formerly universally used. For winding from mines also horizontal engines are chiefly used, and are fitted with sensitive valves, reversing-gear, and powerful brakes, so that though they run at a high speed they can be easily stopped and reversed. The ordinary type of horizontal engines may be described as having a long cast-iron bed-plate, on which the cylinder, guides, and plummer-blocks are bolted; the bearing-surfaces on the bed for all these parts being in the process of manufacture conveniently planed at one operation. **Position of feed-pump.** The feed-pump is, in some, placed vertically under the crank-shaft, from which the necessary power is taken by an eccentric; in other cases the feed-pump is placed horizontally by the side of the guides on the bed-plate, and worked by the piston cross-head. The pump is more accessible by the latter plan, but if breakage takes place it is more inconvenient there than by the former plan. The above form of engine is usually adopted for sizes between 10 and 60 horse-power. **Cost of horizontal engines.** Horizontal engines of this kind cost from £12 to £14 per nominal horse-power for sizes between 8 and 20 horse-power, and the cost decreases per horse-power as the size increases, so that with an *See* H. P., *page* 568. engine of 50 horse-power, the cost would only be about £10 per horse-power. The exact price at any time varies, not only with the **Extra charges.** *See also page* 451. cost of materials and labour, but with the number of extra fittings required. Thus, a link-motion reversing-gear, as for winding-engines, or special pulleys or drums, involves extra charges. The above **Cost of boilers.** prices are for engines only, and the cost of Cornish or Lancashire boilers with their fittings and connections is, for the smaller sizes, more than that of the engine; but above 12 horse-power, the proportionate cost of boilers becomes rather less. There is, however, no fixed relation between the prices of engines and boilers, as obviously much depends on the kind of boilers, and the other circumstances of **Small engines purchased ready made.** each case. Engines up to 20 horse-power can either be purchased ready made, or can soon be finished when ordered. But engines of higher power are seldom made except as ordered, and the manufacture generally requires from one to three months' time.

Engines above 50 H.P. made in pairs. When more than 50 horse-power is required, the question arises whether a pair of engines is not preferable; and it becomes difficult to suggest rules for guidance which are not likely to mislead, as in almost all such cases there are special circumstances which have to be considered. Where there is a likelihood of increased power becoming necessary in the future, the engine-house and foundations **Or second engine added.** may be constructed with a view to the after addition of a second engine to the crank-shaft of the first; and the crank-shaft may be made long enough for such addition, and strong enough to transmit the additional power.

Cheap horizontal engines. The great demand for horizontal steam-engines of small power has led several manufacturers to establish standard patterns of their own, which by constant repetition can be made very cheaply. The



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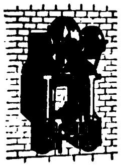
parts are few and simple; the bed-plate is short, because the cylinder overhangs, and one principal casting suffices for bed-plate, guides, and plummer-block. This form of engine is chiefly adopted for sizes between 3 and 20 horse-power, any of which can be purchased ready made for about 20 per cent. less than the horizontal engines just described.

Vertical engines.

Save floor space.

Vertical engines are very useful where floor area is limited, as considerable power can be obtained in a small space. But unless the walls can be utilised for the attachments wide base-plates are needed, and the foundations are more expensive than those for horizontal engines. Small vertical engines are made in various forms, as detached engines with separate boilers, or as complete self-contained semi-portable machines with boiler and engine in one. Wall engines may be described as horizontal engines placed vertically, and bolted to a wall instead of to the ground, as the general arrangement of the parts is in other respects similar. When a strong wall is available this mode of fixing the engine is often very useful, as the crank-shaft can be continued directly as a line of shafting at a convenient height from the ground. It is becoming usual, in large engineering factories where there are numerous machines, to erect several small engines instead of one large engine, so that the machinery in any one department can, if necessary, be kept going without working the whole engine power, thus reducing the inconvenience from accidents by dividing the risks over numerous engines. In cases like these, where there is a range of workshops side by side, the engines working in each gable wall may be made a symmetrical feature in the architectural design. Wall engines cost about the same as horizontal engines.

Wall engines.



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See page 484.

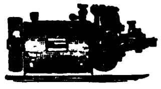
High-speed engines.

Coupled to machines.

Examples.

Limits of speed.

High-speed engines are a modern development of the steam motor specially contrived for giving power to certain kinds of machines to which the required velocity can be more effectively conveyed by direct connection with a steam-engine than by belts or toothed wheels. Centrifugal pumps, ventilating fans, hydro-extractors, circular-saws, small screw-propellers, and, more particularly, electro-dynamos, are examples of such machines in which the main shaft is a prolongation of that of the steam-engine. Even well made engines of ordinary kind cannot run steadily at more than about 200 revolutions per minute, the reciprocal movement of the crank and the centrifugal movement of the fly-wheel causing vibrations when such a speed is exceeded. But by a peculiar design and arrangement of the parts, from 400 to 600 revolutions can be obtained from the high-speed engines above referred



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Mode of working.

Run smoothly and quickly.

to, which are generally placed vertically. In some cases three cylinders are fixed side by side, working on to one crank-shaft; in another three steam cylinders are arranged radially round one shaft, to which the three pistons converge, and to the one crank of which they give motion. In the latter the pistons are single-acting, the steam being admitted only on the hinder side; and as the pistons are made deep enough to guide themselves in the cylinders, the connecting rods are hinged directly on to the piston, after the manner of trunk-engines. As there is no "dead centre" a fly-wheel is unnecessary, and the connecting-rods being always in compression, the engine runs more smoothly than is possible in the case of an ordinary engine where the connecting-rod is alternately pushing and pulling the crank-pin.

Rotary engines.

Not successful.

Steam-turbines.

Examples.

Ever since steam-engines were first introduced, there have been constant attempts among engineers and others to design an effective *Rotary* engine; and the problem is fascinating, because a continuous circular motion is obviously more desirable—if it can be satisfactorily obtained—than a reciprocating motion which has to be changed into a circular one. Although many rotary engines have proved successful in the sense that they have done effective work, none of those invented are likely to supersede the ordinary types of engines. But there are occasions when a speed is required much beyond what any engine with reciprocating movement can give, and for these the Parsons steam-turbine affords a useful and efficient motor. Running at from 3000 to 5000 revolutions per minute, they have been used principally for electric dynamos for the lighting of steamships, and as portable machines for search lights, but also for pumps or ventilators in mines, screw-propellers in launches, and they are generally available for any purpose where considerable power is required in small space. The earlier of these turbo-motors consumed much steam in proportion to their power, but by an ingenious system of compounding, the expansive force of the steam is utilised with as much economy as in ordinary reciprocating engines. A steam-turbine giving 8 brake horse-power only occupies a space 3 ft. 9 in. long, 15 in. wide, by 3 ft. high, and weighs 1200 lbs., while one of 20 horse-power measures 5 ft. by 15 in. by 4 ft., and weighs 2000 lbs. When applied to electric lighting a complete machine with dynamo-generator equal to 200 electric horse-power occupies only 40 square feet, and weighs only 5 tons.

Catalogues and price lists.

The publication of catalogues and price lists has done much to remove the mystery which formerly attended the manufacture of steam-engines, and has greatly extended the facilities for export. The commerce in engines of uniform pattern also allows the use of special tools and economical methods. Formerly, engines were designed only for their ultimate purpose, and machinery was applied to the manufacture only so far as the shape of the various parts permitted. Now, to a considerable extent, the tools and methods are the starting point, and the parts of the steam-engine are designed to meet their capacity. The use of the lathe has especially been extended, and operations formerly performed by hand-labour, or by slowly-working planing machines, are now more quickly accomplished by rotary motion. The uniformity which cheapens price does not, however, allow of such exact adaptation to the purpose in view as is possible where each engine is made specially; for the shape and dimensions offered by the manufacturer must be accepted; and alterations, if demanded, generally involve an extra cost, out of proportion to the advantages obtained. There are, however, certain modifications which manufacturers allow, with little or no addition to the price—such as making the engine right or left-handed, and altering the position, or diameter, or weight of the fly-wheel.

Engines of uniform kind.
See LATHES, *page* 737.

Uniformity not always convenient.

Modification allowed.
See also page 592.

The diversity afforded by the catalogues of numerous manufacturers oftens enables a purchaser to obtain an engine suited to his purpose; but the number of manufacturers who are on equal terms in regard to quality is very limited. The custom of buying from catalogues is followed mostly for steam-engines of less than 30 horse-power; for as the number of engines of similar kind that can be sold becomes rapidly less when 20 horse-power is exceeded, manufacturers are seldom disposed to keep large engines in stock; and, moreover, the necessity for variations of established patterns and dimensions, and the expense of obtaining them, become greater as the power increases. Engines beyond 30 horse-power are therefore seldom kept ready made, but are made to suit exactly the purpose of the purchaser. As, however, a considerable portion of the original cost of an engine is that for drawings, templates and foundry-patterns, manufacturers always endeavour to utilise those they have; and it is almost always advantageous for purchasers to adopt such patterns. Not only is the cost so reduced, but manufacturers and their workmen do best what they are accustomed to do. For this latter reason it is generally inexpedient to present to the manufacturer

Diversity of engine.

Ready made engines.

Seldom exceed 30 H.P.

Standard patterns.

Accustomed kinds cheapest and best.
See page 434.

the designs of another for reproduction; a course sometimes followed by those who wish for competitive prices.

Dimensions of engine stated by seller. *See page* 569. *See page* 576. **Also the assumed pressure and speed.**

It is usual in the commerce in steam-engines for the manufacturer to state the leading dimension to the purchaser, or, at any rate, the diameter of the cylinder and the length of the stroke, because these dimensions, with a given working pressure of steam, afford an approximate measure of power and value. The particulars which determine the value of the boiler have been already described. The manufacturer should be called upon to state the pressure of steam and rate of speed which he recommends and on which he has based his calculations, and it is generally desirable to adopt these in the actual working. Particulars of this sort are frequently given even in the printed catalogues of engine makers; and when the purchaser is satisfied with the reputation of the manufacturer, he requires no more. **Other particulars required.** Where the engine is one offered by the seller for a particular purpose, and especially where the expenditure involved is considerable, it is usual to give other dimensions also, and to enumerate the various accessories. While, however, these points do much to allow an appraisement of value and a comparison of prices, the responsibility for their fitness for the specified purpose should be left with the manufacturer. *See page* 423. **Difficulty of comparing tenders.** Even then, unless there be some knowledge of, and confidence in, the seller, it is almost impossible to decide as to the comparative merits of various tenders. In some cases, if the weight to be supplied could be ascertained, it would immediately disclose that one maker intended to give a machine more solid and substantial than another. **By weight.** On the other hand, if strength is to be obtained by thickness and weight of parts rather than by excellence of material and design, such a comparison will mislead, **Not conclusive.** for mere weight may be given on account of doubt or errors in design, may involve undue friction in working, consume excessive power, and may be allied with rough workmanship. **Examination and inspection.** An examination in the first instance by an engineer, of the drawing and specification, and an inspection afterwards of the workmanship and movement under steam, may in many cases be the only sure tests. **Engine tested by actual working.** It is for the above reasons that there is generally so much wider divergence in numerous tenders for steam-engines and machinery designed by the respective competitors than in those tenders based upon some common design or bill of quantities. *See pages* 414, 416.

Engines fixed and tested *in situ* by maker. When a stationary engine is bought for use in the country of manufacture, the maker is generally employed to fix it in place, and to verify, by running it under steam, the accurate fitting of the moving and bearing parts. For export, engines not exceeding 30 horse-power can generally be so tested in the factory, and this should be made a condition of purchase. But at some factories engines up to 100 brake horse-power can be readily tested under steam. The engines should be worked continually at full speed for several hours, and then the piston, slide-valve, and other wearing parts examined, and, if necessary, eased or adjusted. Preparatory working of this sort sometimes affords an opportunity for measuring the strength of the engine; but such a trial demands very great care and watchfulness to render it trustworthy, and the boiler, on which the efficiency of the engine so much depends, cannot, unless it be self-contained, be easily tested. If the engine has been properly made, the dimensions and steam pressure will sufficiently demonstrate the available power.

Or tested at factory when for export.

Cheapness not to be measured by price.

Engines of the same nominal power differ so widely in design and workmanship, that a mere comparison of price is worthless as a measure of cheapness. Among the circumstances which should determine a choice, the following almost always apply:—

Other circumstances.

Length of stroke.

Speed.

The stroke of the engine should be long enough to afford the desired power at a proper piston-speed, without an excessive number of revolutions. As a general rule, it may be said that high speed gives the greatest power for a given size of engine, and that a moderate speed gives the best results for a given expenditure of fuel.

Adjustability.

The slide-valve gear should not only allow for the use of steam expansively, but should be capable of adjustment; and the apparatus for doing this should be simple for the engine-driver, and not liable to become deranged. The governor or other arrangement for regulating the speed should be automatic, and not depend on leather belts.

Strength of framing.

The framework and fixed parts of the engine should be strong; the joining surfaces well machined, and the bolts tightly fitted, so as to prevent the parts of the engine shaking loose or out of true line.

Bearings.

The bearings and other moving parts should be of ample area, and so well fitted as to cause the minimum of friction in working.

Wearing parts.

Provision should be made in wearing parts like the guide-bars, for adjustment and taking up the wear.

Use of steel and gun-metal.

Certain parts of the engine, such as the piston-rod, connecting-rod, and crank, should be made of high-quality wrought iron or steel; and there should be a proper amount of gun-metal (brass) in the bearings and other parts.

Case-hardening of joints. The moving joints, such as in the link-motion, valve-gear and governor, should have steeled surfaces, or be case-hardened, so as not to wear loose. Although assurances as to case-hardening are almost always given by engine-makers, it is a troublesome operation often imperfectly performed; but when properly done it adds greatly to the durability of the engine, for it renders the surfaces as hard as the hardest steel, without the accompanying brittleness.

Extra parts and fittings. It almost always happens in the setting to work of a steam-engine that extra parts or fittings are needed beyond those actually pertaining to the engine, and the mere printed price of a manufacturer or dealer seldom includes more than the engine itself, for as the accessories or **Vary according to purpose.** extra parts vary with each engine, the price must be determined by the necessities of each case. An engineer or manufacturer who is consulted by a purchaser, and made fully acquainted with his wants, ought to specify and enumerate all that is required; but very often **Insufficient information.** prices or tenders are based on insufficient particulars: this most frequently happening with inquiries from abroad. As the price of the engine alone may form but a small proportion of the whole expenditure, and a tender apparently the cheapest prove afterwards to be the dearest, it is very desirable at the commencement to ascertain and describe everything that is wanted, so that one contract may serve for all. *See page* 459.

Unless otherwise specified, a steam-engine, if without boiler, does not include any piping, and even when a boiler also is purchased, close contiguity of boiler and engine is assumed, and only the pipes **Steam pipes extra.** necessary under such circumstances included. The extra parts, which vary in almost every case—but of which some or all are generally required—are the steam-pipes between engine and boiler, exhaust-steam pipes, suction and delivery pipes for feed-water, and the holding-down bolts; and all of these differ according to the arrangement and dimensions of the buildings and foundations. **Reversing gear.** Link-motion reversing-gear, as necessary for a winding-engine, is not supplied except where it, or the purpose which would render it **Secondary shafts.** essential, is specified; nor are secondary shafts, wheels or pulleys, for transmitting the power of the engine. Among other additional parts which may be required, and which involve extra cost, are **Special extras.** peculiar or sensitive governors, safety-valves, or automatic regulating apparatus of a novel or exceptional kind. The extra parts are sometimes entirely outside the special functions of an engine-maker; girders, columns, or other structural ironwork in connection with the building, being frequently required.

Duplicate parts.
See pages 451 & 576.
Specially needed in distant countries.
Spare boilers.

The supplying of duplicate parts is a question quite distinct from the foregoing, and one that depends principally on the destination of the engine, and the facilities for obtaining what is wanted as the need arises. Few or no duplicate parts need be purchased with engines for use in the country of manufacture, but for distant countries it is usual to purchase with the engine spare bearing-brasses, fire-bars, and even a spare piston; while in cases where the temporary failure of the engine would involve great loss or inconvenience, a duplicate engine is kept ready for working; and it is a common precaution—even in the country of manufacture—to have one or more spare boilers available for use while those that have been working are being cleaned or repaired.

Carriage to site.
Size and weight of pieces.
See pages 445 & 449.
Skilled labour to erect engines.
See page 450.
See page 578.

The carriage of an engine to its destination often involves trouble and expense, and especially so if the engine be one of considerable power, or if the means of transport be limited. But while it may save much cost in carriage to have small or light pieces, such economy may be too dearly purchased. For instance, it is a great advantage to have an engine bed-plate in one piece, so as to ensure solidity and firmness in all the parts connected to it; and a double rate of carriage may be amply justified to prevent the division of such a piece. Sometimes, however, an engine is sent almost entire, with cylinder fixed and slide-valve adjusted. The skilled labour in re-erection, which division for transport of such parts renders necessary, is sometimes very expensive. Thus a boiler, if divided into pieces, not only cannot be tested satisfactorily at the manufactory, but requires skill, not always available at the site of erection, for riveting and caulking the joints. Water-tube boilers are convenient in such cases.

Lightness of parts.
Extra strength required abroad.
See page 451.

In a well-designed engine the parts are kept as light as is consistent with strength, not only to save expense in manufacture, but to reduce to a minimum the weight of the machine and the power necessary to work it. But in engines made for export to foreign countries, where repairs are not easily executed, and where the inconvenience or loss from a "breakdown" is serious, the ordinary margin of safety may sometimes be increased with advantage.

Choice of engine, how determined.
Purpose and power.

The kind of steam-engine which is best suited for export to a foreign country can only be properly determined on the basis of the following particulars, of which some or all, as they may be found to apply, should be furnished by the purchaser. These particulars should be considered in connection with the points enumerated on pp. 567–8.

Connections needed.

1. A description of the *Machinery* to be driven and its speed so far as will allow a proper provision to be made for connecting it to the engine, or transmitting the power. If the machinery is already provided, sketches and dimensions of the shafts, wheels or pulleys to which connection is to be made must be given, and their speeds. If there is any reason why the engine should be right or left handed. (the crank-shaft on the right or left side, looking from the cylinder), it should be stated.

Arrangements for transmitting power.

Buildings.

2. A description of the *Building* in which the engine is to be fixed, or if a house, chimney, or foundations have to be designed, particulars of the building and roofing materials available. This design depends also on the nature of the soil on which the engine and boiler house are to be built; whether the soil is dry, or can be drained; whether it is liable to floods; and on any other circumstances by which the level and nature of the foundations can be decided.

Foundations.
See page 471.

Kind of fuel.
See page 527.

3. The kind of *Fuel* which is to be used, and its kind and quality as compared with some standard British coal. If coal is not obtainable, a description should be given of the wood, saw-dust, peat, oil, straw, or refuse available, and their comparative cost and abundance.

Kind of water.

4. The *Water* available for the boiler, or for a condenser; its quality and abundance; the level or situation of the reservoirs in regard to the engine; whether in a well, pond, river, tank, or in pipes. If from some public source, the head or pressure; if to be purchased, the cost of the water, and how it is measured.

Nature of supply.

Carriage to site.
See page 449.

5. The facilities for *Landing* machinery at the port of arrival, especially for heavy or bulky pieces; the import duties payable, and how assessed; the nature of the roads and means of *Transport* from the port of arrival to the site.

Workmen.
See page 450.

6. The kind of *Workmen* available for erecting the machinery, for acting as engine-drivers and stokers, or as mechanics for making repairs.

Workshops and facilities for repairs.
See pages 408, 451.

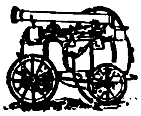
7. The kind of engineering factories, foundries or workshops—if any—available for repairing or replacing damaged or worn-out parts, and the time which would be needed to import fresh parts. The importance or otherwise of keeping the machinery always at work, and the periods of rest available for repairs. This information is necessary, not only to the proper choice of engine and boiler, but for deciding on the duplicate parts which shall be provided. In the case of large engines with heavy pieces, particulars should be furnished of

the tools and plant available in the country, such as cranes and winches, and engineers' tools for fixing the engine in place.

See Chap. XIX. TRANSMISSION OF POWER.

There are cases where a steam-engine cannot apparently be applied, but where it may be possible and expedient to bring steam from a considerable distance; and compressed air may even be used to work an engine originally constructed for steam.

Portable engines.



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Maximum power. *See* **H.P.** *page* 570.

Drawn by horses.

Or propelled by steam. *See page* 599.

How used in agriculture.

By contractors.

Portable engines (locomobiles), introduced first for agriculturists, are employed for a variety of purposes in all parts of the world. They are shaped like a locomotive, and have also a multitubular boiler, but the engine is fixed upon, and not beneath, the boiler. Portable engines are usually made with one cylinder up to 10 nominal horse-power, and above 12 horse-power always with two cylinders. The double-cylinder arrangement has the advantage of distributing evenly the strains from the engine on the boiler, and of giving a more equable motion. Although portable engines are made up to 30 nominal horse-power, their use becomes of doubtful expediency beyond 20 horse-power, and the great majority of those made are between 6 and 12 horse-power. The brake horse-power is generally three times the nominal horse-power. Fitted with wheels and axles like an ordinary wagon, the portable engines can be drawn from place to place by horses; and being complete and self-contained can be set to work at any time. The inconvenience of providing horses for drawing them has led in many cases to the substitution of self-propelling gear on the engine itself. This arrangement is, however, subsidiary, and not of primary importance as in a traction engine. No special skill is required to manage portable engines, and experience has proved them to be very free from liability to accident. In agriculture, portable engines are used for corn-thrashing machines, for cutting and bruising cattle-food, for the haulage of steam-ploughs, for the raising of water for irrigation, and for the ginning of cotton. By contractors they are used for lifting, pumping, sawing, pile-driving, and mortar-mixing; by miners, for winding, pumping, and ore-crushing; and for all sorts of purposes and places where engines are wanted for only temporary or experimental service. There are districts in some countries where the need for such engines is greater than in Great Britain, and the engines in use are proportionately more numerous. Even to refer to Europe alone, portable engines of English manufacture may be counted by hundreds, driving thrashing-machines in the large corn-growing districts of Russia, Turkey, Hungary, and Italy; while

In corn-growing countries.

For irrigating. *See* CENTRIFUGAL-PUMPS, *page* 626.

in Egypt, for the low lands irrigated by the Nile, amidst the various machinery for raising water, portable engines attached to centrifugal-pumps are the most frequent of all. The improvements which successive years have produced, and which are now combined in a modern high-class portable engine, may be enumerated as follows —

Usual steam pressure.

Up to the year 1865, a steam pressure of from 40 to 45 lbs. per square inch was usual, and in the competitive trials established by the Royal Agricultural Society of England, the maximum was restricted to 45 lbs. per inch; but the advantages of using steam expansively having become manifest to engineers, higher pressures were allowed, and it may now be taken as an axiom agreed to by engineers, although not yet understood by all users, that a pressure of from 60 to 80 lbs. is best suited to the economical development of the portable engine. This method of using high-pressure steam, which may be considered the most important of all the improvements, demanded suitable boilers. By innumerable experiments, carefully recorded, the proper proportions of such parts as fire-box, grate-surface, tube-surface, have been arrived at; and in order to produce a sufficient supply of high-pressure steam from a boiler of moderate size, the combustion is stimulated by the discharge of the exhaust steam into the chimney in the manner usual in locomotives, and a separate steam-jet is generally provided for stimulating the draught before starting. Waste of heat is prevented as far as possible by covering the boiler with felt, on which are placed a lagging of wood and an outer covering of sheet iron; and the feed-water is heated nearly to a boiling point by the exhaust steam, heat being thus returned to the boiler which would otherwise be wasted. By well-arranged bearing-surfaces, balanced parts, and careful workmanship, the friction of the engine has been reduced to a minimum, and its durability increased.

High pressure. *See page* 580.

Improved boilers.

Combustion stimulated. *See page* 575.

Waste heat prevented.

Friction reduced.

Consumption of fuel. *See also page* 572.

In the early trials before the year 1850 the consumption of coal, even in the best portable engines then made, was from 10 to 15 lbs. per effective or brake horse-power per hour; but by means of the improvements enumerated above, the consumption has been reduced to from 3 to 6 lbs., and the effective force brought up to three or four times the nominal horse-power, according to the pressure of steam and speed of the engine. As a consumption so low as 3 lbs. has been only arrived at in competitive trials by skilled engineers and with carefully selected coal, it may be fairly reckoned that a consumption of from 4 to 6 lbs. will be necessary under ordinary circumstances. If the

Minimum amount of fuel consumed.

coal be of inferior quality, or if the combustion be forced too much, the consumption will be greater. The actual power given out by the engine, as measured by a dynamometer or a friction-brake, and not the gross or indicated horse-power, is that which has been adopted for comparison; and this must be taken into account when comparing the service of a portable engine so measured with other engines whose "indicated" horse-power is alone ascertained. Among English manufacturers it is usual to give 10 circular inches of piston area for each nominal horse-power, so that an engine of 8 nominal horse-power would have a 9 in. cylinder, and so on. But there is so much room for misunderstanding and discrepancy in stating the nominal power of an engine, that some makers abstain where possible from rating their engines so, and prefer to state the actual nett or effective power given from the fly-wheel when the steam is at a certain pressure. In the United States it is usual to rate engines for sale by the gross indicated power, which is misleading unless accompanied by other particulars. Where the power as measured by the cylinder capacity appears high, the sufficiency of the boiler to maintain such a power without undue forcing of the fire must be considered. Where wood fuel is used, a weight of about three times that of coal may be reckoned as an average consumption. For burning wood, the furnace-door and fire-box are made larger than for coal, and a spark-catcher is attached, the alterations adding about £1 per nominal horse-power to the ordinary price. In some corn-growing countries, where coal or wood is scarce, the straw from the thrashing machine is utilised as fuel by means of an ingenious self-feeding apparatus, so attached to the front of the boiler that the straw is taken into the furnace at a regular and proper rate. In this way about one-tenth of the straw from the thrashing-machine is sufficient as fuel. Engines made in this way cost from £2 to £4 per horse-power extra, according to the exact method and patent royalty. Petroleum engines may be utilised as portable motors where fuel or water for a steam boiler is unprocurable.

See COAL, *page* 527.

Effective H.P.
See page 568.

Diameter of Cylinder.
See page 569.

Boiler capacity.

Wood fuel.

Straw fuel.

Petroleum engines.
See page 606.

The exact repetition of similar parts which the manufacture of similar engines allows, is an advantage utilised to the utmost by the principal manufacturers of portable engines. Special machine-tools and automatic processes have been invented for doing what in other cases has been done by hand-labour, or ordinary machines; and by these improved means three distinct results have been obtained—excellence of workmanship; interchangeability of parts (so that when

Methods of manufacture.
See Chap. XXV. MACHINE-TOOLS.

Parts made interchangeable.

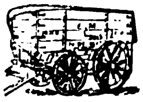
any part is worn out, another kept ready, or sent from the factory to replace it, will fit exactly); reduced cost.

Fluctuations in prices.

Extra charges.

Engines arranged for travelling.

Packed for shipment.



120.

See page 445.

The prices of portable engines fluctuate like those of all other machines, according to the cost of material, briskness of trade and other circumstances. Taking an 8 nominal horse-power engine as representing the kind most in demand, the price during the thirty years ending 1898 ranged from £200 to £280, and the prices of other sizes in like proportion. The following are about the average prices that have prevailed:—4 horse-power, £170; 6 horse-power, £200; 8 horse-power, £230; 10 horse-power, £270; 12 horse-power, £320. But these prices, though inclusive of everything necessary to the working of the engine, are exclusive of all extras, alterations, or duplicates. Thus a feed-water heater, feed-water injector, expansion valve, link-motion reversing-gear, spare bearing-brasses and fire-bars, all add to the cost; and from £1 to £4 per nominal horse-power must be added if these are required. For travelling on the road, or by railway, the chimney is lowered, and the engine is covered with the tarpaulin which forms part of its ordinary equipment, no other packing being required. The same plan applies for short voyages, when the engine can be taken on the deck of a steamer, except that the detachable fittings are packed in a small case. For long voyages, the wheels and chimney are detached, and the engine must be packed in a case, at a cost of about 3 per cent. on the price of the engine. On landing, and if needed for inland transport, the wheels can be attached without unpacking the engine. The weight of portable engines packed, ranges from about 3 tons for an engine of 4 horse-power, to 10 tons for one of 20 horse-power; but the measurement tonnage, at the usual rate of 40 cubic feet to the ton, is about double these weights.

The purchase of portable engines.

Important points enumerated.

See page 583.

The manufacture of portable engines forms a special trade, and English-made engines stand first both in regard to design and quality. It is expedient to purchase only from manufacturers of known reputation; even in first cost inferior engines are but little cheaper. Such engines soon deteriorate; and in case of re-sale the absence of the name of a good maker lowers their value even more than at first. The importance of well-proportioned parts, good material, and workmanship, so necessary in all steam-engines, is enhanced in the case of portable engines, which often have to bear very rough usage, and if defective, soon wear out. The quality of the iron and brass, the use of steel where beneficial, the accuracy of the fitting, and the proper case-hardening of the joints, are all points which determine value. The choice of a portable engine depends on the following circumstances:—

Power required.

1. *The Power required.* It is always economical to have ample power, as an engine and boiler are soon worn out if they are forced above their proper capacity. The pressure and piston-speed specified by the maker as best should be adhered to as far as possible. The power can be approximately calculated if the work to be done is described; thus, if for a thrashing-machine, its kind, size and the name of the maker should be given; if for a circular-saw, its diameter, speed, and the kind of timber; if for pumping, the kind of pump, the quantity of water per hour, and the height to which it is to be raised.

How arrived at.

See page 613.

The purpose.

2. *The Purpose for which the engine is intended.* Although the same portable engine may be applied to a variety of uses, certain minor arrangements can be made with advantage to meet special cases. Thus the diameter of the driving-wheel may be made to suit the pulley of a machine to which the power is to be applied. If for winding for a mine, reversing apparatus becomes necessary. The relative position of the engine and machine to be driven must be considered so far as it will determine whether the engine is to be right or left handed. Unless otherwise specified the fly-wheel, which serves also as the driving pulley, is generally on the left side of the boiler looking from the firing end. The engines can be constructed either way, and some makers arrange the crank-shaft so that the fly-wheel can be fixed on either side at will.

Engine may be modified to suit.

Climate and locality.

See also page 452.

3. *The Climate and locality.* The choice of iron or wood for the wheels, and certain other minor points, can be modified to suit extremes of climate. If the engine is required in a country where repairs are difficult, certain spare or duplicate parts should be provided.

The kinds of fuel.

See COAL, *page* 527.

4. *The kind of Fuel and Water to be used.* Unless otherwise specified, the furnaces are made of the form and dimensions suitable for coal of average English quality. But almost every kind of fuel can be used—wood, turf, peat, dung, straw or refuse cane, and if the kind of fuel be known, the furnace and boiler can be made accordingly. The kind and abundance of the water are important points.

Mode of draught.

5. *The mode of Draught.* Shafts or poles for a pair of horses or oxen are supplied with the engine, and if above 7 horse-power,

double shafts if preferred. The nature of the attachment, and whether for horses or oxen, should be stated by the purchaser.

Portable-engines often misapplied.

The advantages afforded by portable engines lead sometimes to their misapplication. The two distinguishing features in a portable engine, and to which it owes its value, are its self-contained completeness; and as a result of this, the facility with which it can be moved from place to place. But though this second quality, the portability, is that for which these engines were designed, and is that which really justifies their use, they are in foreign countries often chosen where no portability is needed, and because only of their completeness and readiness. In many of such latter cases it is a mistake to use portable engines made in the ordinary form. It is doubtless a temptation to any one who requires steam power, and especially where the purchaser or user is not an engineer, to procure an engine ready for use, which requires no foundation, house, or buildings, and not even an engineer to set it to work. Where the engine is intended for a merely temporary purpose these advantages are real; but for the purpose of a permanent stationary engine they are delusive, and in the end involve considerable unnecessary expense.

Portability not required.

Fixed engines preferable.

See page 450.

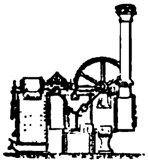
Boilers of portable engines wear out sooner than engine.

A portable engine resembles a locomotive in its multitubular boiler, and, as already explained, these boilers wear out more rapidly than those of simpler kind. The fact that steam can be generated quickly, and that a comparatively small boiler can produce a great deal of steam, is not generally of primary importance in a fixed engine, except where mere space is very valuable or buildings expensive. A fixed horizontal engine has, under ordinary circumstances, a much longer life than a multitubular boiler; but where it is affixed to the boiler, as in a portable engine, its life ends with it. Moreover, an engine fixed to a boiler—however careful the workmanship—is not on a sufficiently solid foundation; its parts sooner become loose and irregular than in a properly fixed engine, and moreover they shake the boiler and hasten its destruction. These facts are so obvious that no engineer would propose to so construct an engine and boiler, except to satisfy the exigency of portability, or to render it self-contained. The difficulties of erecting an engine in its place, of setting a detached boiler and of connecting the pipes, are often over-estimated, for if proper instructions be supplied by the manufacturer of the engine, the purchaser, with the assistance of an intelligent

Engine shakes loose.

Fixing of engines.

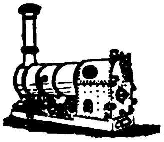
Portable engines made permanent.



121.

French engines.

Complete bed-plate on boiler.



122.

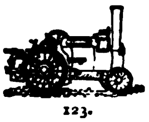
Engine fixed below boiler.

blacksmith and mason, can effectually set such an engine going. To meet these objections various forms and degrees of compromise between fixed and portable engines have been devised. The first is that of substituting rigid iron supports for the wheels of an ordinary portable engine. These supports allow the engine to work more steadily than if on wheels, and at the same time the whole machine remains self-contained and complete. It can be carried whole by ship, and to its destination, and can be removed if the necessity arises. A level and firm base should be provided for this class of engine. In French *locomobiles* it is customary to fix the working parts of the engine on one bed-plate bolted upon the boiler, so as to save the latter from strain during working. But the desired end is not entirely gained, and the engines, being less simple and accessible than those made according to the English method, have not been adopted elsewhere. In England another plan is that of placing the engine below the boiler, and on the same iron bed-plate with it, on a base of masonry or timber. By this means the advantage is obtained of having the engine on a solid base independent of the boiler, so that the latter can be removed or replaced; the machine, at the same time, remaining complete and self-contained. There is the same disadvantage in this plan as in a locomotive, that the parts are not easily accessible, and that leakage from the boiler and dust from the furnace damage the engine; although, if the boiler be well made, there need not, with proper attention, be any leakage. Engines of this class, or of the one described above, are useful in confined spaces, such as mines or small factories.

Engine separate from boiler.

The next step is to separate entirely the engine from the boiler, while retaining the latter in its ordinary locomotive shape. This is in effect a horizontal engine with separate multitubular boiler, as already described, and need no longer be discussed under the head of portable engines.

Traction-engines.



123.

Road engines.

Traction engines, as a combination of the locomotive and portable type, need a separate description. In form of boiler, and in having the engine fixed to the boiler, they resemble portable engines, but are much more expensive. Traction engines are of different kinds, the main distinction being between those where the haulage of heavy loads is the primary object, and known in England as Road locomotives, and those in which power to be given to another machine is the chief consideration, and the moving from place to place with

Agricultural engines.

the machine behind it is subsidiary. The latter kind are generally known as Agricultural locomotives. The first kind is also useful to the agriculturist in connection with certain forms of steam-ploughing, to contractors or others for hauling wagons, or to an army in the field for drawing heavy guns; the second is used for drawing corn-thrashing and other machines (to which when they are at work it gives power) from one farm to another.

Broad tire wheels.

Soft ground.

See BRIDGES, *page* 148.

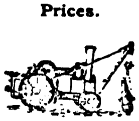
Weight of engines.

Haulage power.

See LOCOMOTIVES, *page* 692.

Prices.

Great improvements have been made in traction engines, and there is no doubt that where, as in Great Britain, the legislative restrictions to the use of steam-engines on the high roads are removed, they will be utilised much more than hitherto. The wheels are arranged with broad tires, which consolidate rather than cut up a road, and the earlier plan of equipping the wheels with rails, which were laid automatically, has been abandoned, as it was complicated and troublesome; and although difficulties often arise in passing over soft ground, they can be overcome, as, in case of need, planks laid temporarily as a road will suffice. In some countries intersected by creeks and rivers, the use of heavy traction engines may almost be prohibited by the weakness of the bridges or by the yielding nature of the river bed where a ford is the only means of crossing. As a type of the heaviest engine, one weighing 22 tons, distributed over a wheel base 14 ft. 3 in. long and 9 ft. 6 in. wide, may be taken as an example, but much smaller engines are generally used. It may be taken as an approximate guide, that a traction engine weighs about one ton per nominal horse-power, and that where the gradients do not exceed 5 per cent. it will draw on a good road twice its own weight, or three times its weight on a level; but much depends on the condition of the road. Traction engines for use as road locomotives are made generally from 4 to 12 horse-power; and for hauling steam-ploughs from 10 to 20 horse-power; the prices ranging from about £400 for an engine of 4 horse-power, to £700 for 12 horse-power, and about £1000 for 20 horse-power. The smaller engines are sometimes fitted as cranes, a projecting jib being attached to the front of the boiler. By this means the engine can lift heavy loads into the wagons, as well as haul the load. This crane arrangement adds about 10 per cent. to the cost of the engine. Compressed gas for giving light for night travelling can be stored and carried on the engine; but as in some cases a small dynamo is attached to the engine for providing electric lighting when the engine is doing stationary work, a powerful head-light can be obtained if necessary.



124.*

Electric lights.

Four-wheel wagons to carry four tons, fitted with brakes of a kind suitable for haulage by a traction engine, cost about £70, and for six tons about £80. If only the wheels and other ironwork are required, the cost is about one-third less. The following particulars are necessary to a proper choice of a traction engine and wagons: (1) The *Purpose* for which it is required and the *Weight of load* to be hauled; (2) the quality and *Gradients* of the road and the strength of the *Bridges*; (3) the kind of *Fuel* to be used; (4) if for export, the facilities for shipment and landing.

Wagons.

Choice of engine.

The steam *Road roller* is another ingenious adaptation of the road locomotive, and is successfully used in London and other large cities for consolidating newly-laid macadam. These engines are made to roll a width of from 6 to 7½ ft., with rollers generally about 5 ft. diameter: the total weight is from 6 to 15 tons, and the cost from £500 to £800 each. The strength of bridges has to be considered, as in the case of traction engines, but the greater width of wheel modifies the effect on the road surface.

Road rollers.

Weight and price.

It may be stated as a general rule in the purchase of steam-engines, that those of less than 30 horse-power may be selected with advantage from the stock of a manufacturer or dealer, and that the cheapness and convenience which such a course allows outweigh the minor objections to accepting a fixed type and a ready made machine. But the earlier question has also to be considered whether it is expedient to adopt a steam-engine at all, and whether a gas-engine or some other kind of motor should not be preferred. The expenses and inconveniences which attend the use of a steam-engine bear heavily on those of small power. The skilled attendance required, the risk and inconvenience of fire and smoke, the difficulty of examining and repairing small boilers, the loss of time between the lighting of the fire and the setting to work, frequently justify the opinion that steam-engines are not the best suited for small industries; although for engines above 10 horse-power these inconveniences did not, in the absence of alternative methods, prove sufficient to outweigh the advantages gained. Since the great improvements that have been made in gas-engines and electric motors the comparison has become very different, especially where cheap gaseous fuel or an electric current from a public supply is available, and these more modern methods have to be considered for large powers also. On the other hand, there are cases where the drawbacks to the use of

Small engines bought ready made.

See page 587.

Other motors preferred to steam.

Disadvantages of small engines.

See page 605.

See page 611.

Favourable cases.

Small engines with steam from, large boilers.

See page 484.

Boilers inconvenient.

small steam-engines are lessened by the circumstances attending them. The absence of a boiler is an instance; such a case occurring often in factories and other places, where small engines are used for working machine-tools, and where steam is furnished from a large boiler situated in a safe and convenient place for other purposes. The question then generally resolves itself into one of power-transmission, and the small engine is used because it is judged more convenient to bring power by steam in pipes from a boiler not too distant, than by shafting from a large engine; or because it is preferable to have a small engine available for a single or isolated machine instead of keeping a large engine at work for the purpose; or where, as in the case of a donkey-engine for feeding the boiler of a large engine, not only no separate boiler, but no additional engine-driver is needed. Steam cranes afford another example; the compactness which a small engine allows being obtainable by no other means, and the crane-attendant manages the engine also. But in places where boilers and fires are inconvenient, as in crowded cities, or where the expenses of attendance bear too high a proportion to the advantages obtained, other means are available and have become widely adopted.

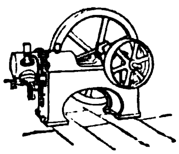
Substitutes for steam-engines.

Gas-engines, oil-engines, hot-air engines, water-engines and electric motors are the alternatives available, each having its respective advantages in particular cases.

Gas engines.

Mode of working.

Gas-engines utilise heat force in a manner quite different from that of a steam-engine, the expansive force being applied by a succession of explosions. The gas-engine has a cylinder with a reciprocating piston from which power is taken as in a steam-engine by a connecting rod to a crank shaft. The cylinder is longer than that necessary for the stroke or travel of the piston, and the gas, mixed with a suitable proportion of atmospheric air to render it combustible, having been drawn into the cylinder by the suction of the advancing piston, is then by the return stroke compressed into the spare or untraversed space at the end of the cylinder and ignited, the combustion being so rapid as to be deemed an explosion. The expansive force so developed propels the piston forward, the flywheel maintaining an equable motion from a succession of such strokes. After the piston has been pushed forward, it, on its return, expels, so far as the length of its stroke allows, the products of combustion, and again moving forward, draws in another supply of gas and the operation is repeated. It will be seen, therefore, that



125.

there is a regular sequence of operations—suction, compression, explosion, expansion, and expulsion. This is known as the Otto or four-stroke cycle, and is that which, with slight modifications, has been adopted in almost all gas-engines up to 1897, the engine being thus alternately a pump and a motor. The gross power of a gas-engine may be ascertained by an indicator, as in the case of a steam-engine. In a well-made gas-engine the initial pressure at the moment of explosion at the beginning of the earlier strokes should be repeated at the later strokes, but this, as will be seen, is not the case in many engines.

Otto cycle.

Power measured by an indicator.

See page 570.

Where gas is available at moderate cost a gas-engine works more cheaply than a steam-engine, there being less loss between the calorific value of the fuel and the effective power developed than is possible in the most modern kind of steam-engine. Up till about the year 1890 the great majority of gas-engines were of less than 20 horse-power, and for such engines illuminating gas obtained from the public mains is almost always used. In well-made engines the consumption of such gas should not exceed 20 cubic feet per effective horse-power per hour, and this at 3 shillings per 1000 feet is about equal in cost to a consumption of 9 lbs. of coal at 20*s.* per ton in a steam-engine. If judged by expenditure of fuel, it will be seen that gas-engines do not differ very much from steam-engines of small power, for it is seldom that steam-engines of from 1 to 6 horse-power consume less than 10 lbs. of coal per indicated horse-power per hour. But if in a steam-engine the fuel needed to raise steam from cold water when the fire is first lighted be taken account of, as well as that consumed during intervals when the engine is idle, the average consumption will, of course, be greater than that measured only when the engine is working, and where the service is intermittent will perhaps be twice as much; while in a gas-engine no such unprofitable expenditure is incurred, as the engine begins to work directly the gas is lit, and the consumption of gas ceases immediately the engine stops working. Gas-engines do not need such continuous and careful attention as the use of a steam-boiler requires, as there is neither fire to be fed nor water level to be maintained, and therefore they are useful in private houses, or in printing works, laundries, or in warehouses for cranes or hoists, and for the latter purpose may usefully pump water for a hydraulic lift. In city workshops, warehouses, or crowded buildings, a gas-engine has the great advantage of freedom from that risk of fire which the use

Cost of working.

Compared with steam-engines.

Conveniences afforded by gas.

Fire insurance reduced.

of the steam-engine involves; and the cost of insurance is not increased by their use in such buildings. They are also used with advantage for pumping up hydraulic accumulators, for opening dock gates or bridges, or wherever the service is too small or intermittent for the economical use of a steam-engine. Even illuminating gas can sometimes be better applied to give power to an electric-light dynamo than for direct use itself for lighting.

Use of illuminating gas costly.

Limits of size and power.

The theoretical economies obtainable by the use of gaseous fuel have long been known to engineers, but even after the expiration of the Otto patents had cheapened the price of engines, they were restricted in practice by the high price of illuminating gas and by the small powers to which the system could be applied. Gas obtained from the public mains is costly if reckoned by its calorific value, because of the monopoly of its supply and by the methods of its manufacture, purification, and distribution. In regard to limits of size and power, difficulties rapidly arise in the Otto cycle of working when 40 horse-power is exceeded. Some of the minor drawbacks common to all gas-engines were overcome during the early years of working, such as in the method of admitting the gas and of igniting it, an incandescent tube being found better than the gas flame or electric spark originally employed. But the main difficulty is in the keeping the cylinder cool and clean, for there is left in the combustion chamber after each explosion a portion of the burnt gases at a high temperature. These burnt gases are not reached by the returning stroke of the piston, and if means were not taken to reduce the temperature, the fresh charge of gas and air would be hotter and more dilute than efficiency requires, the pressure at the moment of explosion would be less, and the power of the engine rapidly diminished. There is even a danger that the new charge will ignite prematurely by the hot products of combustion, and the working of the engine be entirely deranged. It is usual, therefore, to surround the cylinder by an outer casing or jacket through which cold water circulates; and in small engines the volume of gases in the cylinder being small in proportion to the cooling surface so obtained, the reduction in the temperature during expansion and exhaust is sufficiently rapid to allow of a repetition of strokes with the necessary frequency when, as is almost always the case in small engines, illuminating gas is used. For with such gas the proportion of air in the charge is nearly seven-eighths of the whole, and this ensures rapid consumption. For engines of more than 50 horse-

Great heat developed.

How neutralised.

Cylinder water jacket.

power the cost of rich illuminating gas is prohibitive, and the cheaper producer gases when available for power purposes cannot be used if the methods of cooling the combustion chambers and freeing it of the foul products of combustion are those which have been usual with the makers of small engines on the Otto system. The retention of these foul products occupies much space which could be more profitably filled with combustible gases, for, as will presently be seen, a much larger quantity of producer gas is required than is necessary with illuminating gas. When 50 horse-power is much exceeded, not only does the cost of rich illuminating gas become burdensome, but the ordinary method of cooling and cleansing the combustion part of the cylinder, which is effective in small engines, is insufficient, and still more so when diluted producer gas is used. It has, therefore, been customary among the makers of small gas-motors to recommend the use of two or more of such engines, or, at any rate, of engines with two cylinders, when considerable power is required. The only effective means up to 1898 of overcoming the difficulty has been by sweeping or "scavenging" the combustion chamber at each return stroke of the piston by a strong current of cold air, a small part of the power of the engine being applied to compress air for the purpose. This apparatus is, of course, best made as part of the original engine, but may be added with advantage to all engines on the Otto cycle above 50 horse-power. Only by this means can gas-engines run at full power for many hours.

Cheap producer gas.
See page 482.

Cylinders kept cool by scavenging.

Producer gas, which is gas made with a view of developing its calorific qualities, and without the processes necessary in illuminating gas, can be made by the Dowson or other analogous systems from anthracite coal, or from incandescent coke, at a cost in great Britain of about one penny per 1000 feet. Although about four times as large a volume of this gas is required for power purposes as is required with the richer illuminating gas, it will be seen how much cheaper it is if measured by the results obtained. By means of the improved method of "scavenging" and cooling just described, the use of this cheap producer gas is rendered possible for large powers, and the position held by the gas-engine as a prime motor has been entirely altered. Instead of being merely a convenient substitute for steam-engines of moderate powers, gas-engines had, between the years 1890–1897, been made up to 200 horse-power with a large saving in the cost of working over the very best steam-engines, and there are no insuperable difficulties of making them of even larger powers. It may be said of

Cost of producer gas.

Large engines rendered possible.

Cheaper than steam-engines. steam-engines that the consumption of coal is seldom less than 2 lbs. per horse-power per hour, but the gas from less than 1 lb. of similar or even cheaper coal will suffice. Such engines work with the best advantage where producer gas is made on a large scale, but a producing plant for gas of the Dowson kind can be established with advantage for single engines of not less than 50 horse-power at a total cost per engine and gas plant not greater than the total cost of steam-engine, steam-boiler and chimney; while for larger powers the total capital expenditure is less. In either case the consumption of fuel is only one-half that of a steam-engine. But other inventions bid fair to still further extend and cheapen the use of gas-engines. Producer gas made from bituminous coal, which is that found in most colliery districts in Great Britain, and so often used for heating-furnaces in the manufacture of steel and iron, has been unsuitable for gas-engines because of the tar it contained, but by the Mond inventions, which allow the separation of the various products in the coal, not only is pure gas obtained, but by-products, principally sulphate of ammonia, of considerable value are saved, almost recouping the cost of the coal. This process could not, till 1898, be economically applied for small powers, and was useful only for large undertakings where either for heating, or for power, or for both, fuel is required on a considerable scale. An adaptation of such economies to smaller undertakings is probable.

Dowson gas.

Mond gas.

By-products saved.

Brake power of gas-engines. It is usual to reckon the power of gas-engines by the actual or effective force given out from the fly-wheel as measured by a friction-brake. On this basis small gas-engines of 1 horse-power cost about £30, and the rate diminishes as the power increases, so that an engine of 10 horse-power costs about £120, and one of 100 horse-power about £500. In some cases it is found economical and useful to couple two engines tandem to the same shaft, so that by alternate explosions a more equable movement is obtained. This method is, for instance, adopted sometimes with engines over 150 horse-power giving force to dynamos for electric lighting or power transmission.

Prices.

Oil-engines. *Oil-engines.*—Crude oil and oil residuum (Astatki) have been largely used as fuel for steam-boilers in countries where such oil is abundant; notably in Pennsylvania, also on the Caspian Sea, and its tributary the River Volga, where coal is scarce, and generally in south-east Russia for steamers and locomotives. In these cases the oil is injected into the furnace by a jet of high-pressure steam, with

Oil fuel for steam-boilers.

which it is mixed. But the modern oil engines are those which develop the heat force of mineral oil directly without the intermediary of a steam boiler, and these engines may be deemed substitutes for gas-engines in places where gas is unobtainable or is dear, and where petroleum can be purchased at moderate prices. For it is endeavoured to so vaporise the oil as to render it explosive on the same principle as in the gas-engines just described. But at first, although oil-engines were successfully worked on the Otto cycle, it was only accomplished by using a highly volatile petroleum spirit like benzoline, which had the great disadvantage of being dangerous for transport and storage, the risk being greatly increased in a hot climate. The difficulty in using the heavy American or Baku oils of the ordinary kind sold for lighting purposes, was that of disintegrating or breaking up the oil to mix it with the proportion of atmospheric air necessary to render it combustible when vaporised, and it is only since this has been done that the engines may be deemed commercially successful. The vaporiser is the part of an oil-engine which mainly distinguishes it from a gas-engine; and in this respect oil-engines may be divided into two classes, those which vaporise the oil in the cylinder or explosive chamber, and those which have a separate vessel as vaporiser. In the best modern engines the ordinary commercial oil known as kerosene can be used, and as these oils flash only at a high temperature, they are safe for storage and transport.

Vaporised oil.

Otto cycle. *See page 603.*

Heavy oils.

How used.

The engines are made of powers from 1 to 16 horse-power, and in size, appearance, and weight much resemble gas-engines. The consumption of oil is about 1½ pints per effective horse-power per hour, and with oil at 8*d.* per gallon the cost of working is about equal to that of gas-engines when illuminating gas is purchased at 4*s.* per 1000 feet. After the first few strokes the heat for vaporising the oil is produced by the engine itself, but in order to start the engine the heat from a small lamp placed below the cylinder is necessary, 10 or 15 minutes being occupied in this preliminary operation. The vapour is drawn into the cylinder and compressed as in a gas-engine, and then ignited. Steady running is maintained by a fly-wheel and by means of an ordinary governor as in a gas-engine; the quantity of oil admitted being made to accord with the work done by the engine, so that with an engine of a given nominal power the real force may be made to vary within considerable limits. Measured by the actual or effective power as given off from the fly-wheel, the engines cost about £90 for 1 horse-power; £125 for 2 horse-power; £160 for

Limits of size.

Cost of working.

Mode of working.

Prices of oil engines.

3 horse-power; £220 for 6 horse-power, and so on. These engines have been constructed as portable motors for places where fuel or water for a steam-boiler is scarce. The circumstance that an oil-engine cannot be started instantaneously is a drawback to their use, for when an engine is stopped and allowed to cool, the oil has again to be warmed for a re-start. For this reason oil-engines on motor cars and elsewhere are often kept constantly running while on service, the starting and stopping of the machinery they are working being effected by a clutch. The cylinder of an oil-engine requires a water jacket for the same reason as a gas-engine, the quantity of water needed for circulation ranging from 150 gallons to 1500 gallons, according to the size of the engine. But as the same water continues to circulate, and the loss is only by partial evaporation and possible leakage, the daily consumption of water need only be a twentieth of the quantity given above.

Cannot be started quickly.

Water jacket necessary.

Compressed-air engines.
See page 496.

Compressed-air engines have already been described as secondary motors, principally used where steam is unavailing, and where the exhaust air is useful for ventilation, as in mines. But air-engines are also applied to utilise force supplied by a complete system of power transmission in towns, as carried on in Paris and elsewhere.

Hot-air engines.

Hot-air engines, in which the expansive force of compressed air is increased by heating it, offer somewhat the same conveniences as those afforded by the gas-engine. These hot-air engines are complete and self-contained machines (independent of any outside supply), in which a large proportion of the gross power is spent in compressing the air which is then heated; and it is only the extra force due to the heating—less, of course, that consumed in friction—that is gained. In the simplest kind of hot-air engine there are two cylinders, one in which the air is compressed, and the other in which it expands and does its work. At the bottom of the working cylinder is a small furnace for heating the air, and this can be so arranged as to burn with only occasional attention. These engines are most suitable for powers of from ¼ horse-power to 2 horse-power, and can be conveniently used in private houses or small workshops, the smoke being taken either through a sheet-iron chimney, 8 to 12 ft. high, or into an ordinary house chimney or flue. For organ-bellows and other purposes, where but small power is required, the heat may be supplied from gas-burners. An air-engine of ¼ horse-

Compressed air heated.

power occupies about 5 square ft. of ground space, stands 4½ ft. high, with a fly-wheel 2 ft. diameter, and costs about £40, while a 2 horse-power engine—and they are seldom made larger—costs about £140. The consumption of fuel is more than in a gas-engine, but this may be, under certain circumstances, of small consequence if compared with the advantages afforded. Hot-air engines are very useful for either continuous or intermittent pumping, where the quantity of water required is not enough to justify the cost of a steam-engine and the wages of an engine-driver. For instance, at a roadside railway station the water-supply for locomotives may be thus maintained, and the occasional attention of an unskilled workman may suffice to keep engine and pump going.

Sizes and prices.

Examples of use.

Water-engines.
See also pages 198 *&* 493.

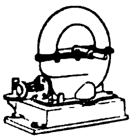
Choice, how determined.

Water-engines.—The methods and advantages of transmitting power by water have been already described. For utilising natural water sources the main points which determine the choice of machine are—the purpose in view and its extent, the height of fall, the volume and continuity of the supply and its liability to restriction at certain seasons. In such cases of natural supply, some form of turbine is generally preferable, water-wheels being seldom used except where there is a rapid flow of water with a slight fall. Where the machinery to be driven requires a rotary motion, a turbine is suitable for any fall between 5 ft. and 300 ft., and as it can deal with a large volume of water it can give more power in proportion to its diameter than any other water motor. For a fall of not less than 10 ft. an efficiency of 60 per cent. can be obtained, as has been proved in many cases by measuring the electric energy generated by a turbine for lighting or power transmission.

Turbines.

Pressure water at Antwerp.
See page 493.

For utilising high pressures distributed in pipes, various kinds of motors are available. At Antwerp, pressure water from the public hydraulic mains is utilised by turbines. In most cases where rapid rotary motion under a steady load is required, the Pelton wheel is preferred, as it gives under most circumstances better results than any other water motor. This is a circular machine in which the water impinges on buckets or vanes, so arranged as to give a net efficiency of from 70 to 80 per cent. according to the constancy of the load. The power of a Pelton wheel of given diameter can, however, be varied within considerable limits. Where the power required is known and remains constant, the supply nozzle can be so made as to restrict the flow of water to the exact quantity required, and by



126.

Pelton wheel.

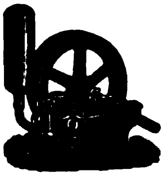
Power, how varied.

means of two or more nozzles the power may be increased with the fullest economy in working. For instance, an 18-in. motor, costing about £60, working with a pressure of 700 lbs. per square inch, and fitted with two nozzles of different sizes, can be made to give off three different powers, the use of the smaller nozzle producing 5 horse-power, of the larger nozzle 10 horse-power, and of both nozzles together 15 horse-power.

Pressure of water in London.

See page 493.

Some pressure between 500 lbs. and 1000 lbs. is generally adopted in hydraulic power mains—in London it is 700 lbs.—but as the Pelton wheel can be used, though with less advantage, with the much lower pressures, say of from 40 lbs. to 100 lbs., usual in municipal water mains, it is necessary to take the actual pressure into account in selecting and adjusting the machine.



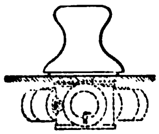
127.
Reciprocating water engines.

Hydraulic power, how limited.

See page 494.

See page 492.

The application of pressure water to reciprocating engines is limited, because the full force is required throughout the stroke of the piston, the water having no expansive force like steam or compressed air, either of which can be economically applied by cutting off the supply when the piston has performed only part of its stroke. It is owing to this restriction that hydraulic power is chiefly applied to direct loads such as the ram of a hoist or crane, and it was in connection with these cranes that Armstrong's accumulator system found its first development. Revolving capstans may also be advantageously worked by reciprocating water-engines at moderate speed, because, though the cost according to power may appear high if compared with that of steam, there is really an economy in the case of machines working intermittently, as they may be used only once an hour or once a day with only a proportionate expenditure.



128.
Hydraulic capstan.

See page 803.

Reciprocating water-engines are also useful for small industries where neither steam, gas nor oil motors are obtainable at moderate cost, and where the only transmitted power at hand is that of high-pressure water. The cost of water-engines may be conveniently stated not according to their power, but according to that capacity for power which the actual pressure available must determine. For instance, an engine with a pair of oscillating cylinders 4 in. diameter, with a stroke of 8 in. and occupying a space of 2 ft. by 1 ft. 9 in. by 2 ft. high, would with a 100 ft. head of water give out 2 indicated horse-power, while the same engine would be strong enough to give out 6 horse-power with a 300 ft. head of water. Smaller engines of this kind, expressing from ½ to 1 horse-power, cost from £20 to £40.

Sizes and prices.

Electric motors.—If a continuous current such as is generated for lighting purposes, as already described, be applied to an electric motor the reverse process to that which generated it takes place, and the current is re-transmuted into mechanical energy, which may be conveniently taken by a belt from the fly-wheel or otherwise, and applied to any purpose where power is required. It will be seen, therefore, that an electric engine is in an entirely different category to that of the heat motors already described, which are self-contained and need only a supply of fuel—coal, wood, gas or oil as the case may be—while an electric engine, in this respect like a hydraulic engine or compressed-air engine, is dependent for its power on a primary motor at a distance; this being the case even if the immediate supply be taken from accumulators. Now that complete systems of electric lighting have been established in cities, and conductor-mains traverse the streets, electric motors can be placed anywhere within the range of such mains and the power paid for at a tariff fixed for an equivalent supply for lighting purposes. An electric lighting company, however, is generally disposed to sell power during the day at a reduced price, so as to utilise its generating and distributing plant at a time when it is not used for lighting. As an example, the current will often, in Great Britain, be sold at 3*d.*, or even 2*d.*, per unit, when the price for lighting is 6*d.* or 7*d.* One unit equals about 1¼ horse-power for one hour, and allowing for loss in re-conversion gives a useful or net effect of fully 1 horse-power.

Electric engines.

See pages 254 & 504.

Not self-contained.

Public electric supply. *See page 266.*

Price of current, how measured. *See page 256.*

Electric dynamo-motors vary in form, and with a given limit of weight and size the power can be varied within a considerable range, according to the speed. The choice of motor in this respect is determined by the purpose in view and the space available. Thus motors running at the moderate speed of 1000 revolutions per minute can be easily connected through one train of wheels to machines, or by belting to countershafts running at 150 revolutions. But electric motors can be profitably employed at much higher speeds than 1000 revolutions, and can be applied directly to such quickly-rotating machines as circular saws or fans.

Various forms of motors.

Power, weight and cost depend on speed.

The weight and cost of a motor of a certain power depend also on whether the working parts are open and exposed or whether they are enclosed and protected. If enclosed it is necessary to provide for ventilation. With these differences a continuous-current motor giving out one effective horse-power may weigh from 130 lbs. to 280 lbs, and cost from £18 to £30; a motor of 5 horse-power

Approximate prices.

from 600 lbs. to 1000 lbs., costing from £40 to £70; a motor of 10 horse-power from 1000 lbs. to 1500 lbs., costing £65 to £100. From 10 to 30 per cent. must be added to the cost of the motor for accessories and spare parts. If high-speed motors are applied to slowly moving machines of course the cost and friction of the intermediary gearing or belting required must be set against the saving in the price of the motor.

Accessories. *See also page* 590.

Motors catalogued.

Electric motors have become so general an article of commerce, that lists of the various kinds and sizes are issued by manufacturers in the same way as are catalogues and prices of steam-engines, and there is no more risk of failure or derangement in the one machine than in the other. The variety of purposes to which these motors can be applied is too great to be enumerated. They form a last link in the chain of electric transmission which is superseding many of the older systems of conveying and distributing power. Besides such stationary purposes as the working of pumps, cranes and machine tools, their use for tramcars and tunnel-railway locomotives is continually extending.

See page 504.

See pages 320 *&* 703.

The current expenses of working dynamo motors are comprised in the daily outlay for the electric current according to the tariff agreed upon, and from 5 to 10 per cent. per annum on the original cost for maintenance and renewals. Where considerable aggregate power is required, as in large factories, it is generally cheaper to install a dynamo-generator worked by a steam-engine or gas-engine. A special attendant for the dynamo motors is seldom required; the parts wear very slowly, and little else but cleaning and oiling is required.

Choice, how determined.

In order to obtain a suitable electric motor, the manufacturer should be informed of the purpose in view, the power required for it, the speed of the machine to which it is to be applied, and also of the system of the electric supply available and its voltage.

[*See also* THE ESTABLISHMENT OF FACTORIES: THE TRANSMISSION OF POWER: COAL.]

CHAPTER XXII.

PUMPS. PUMPING-ENGINES. FIRE-ENGINES. TANKS. PIPES. TUBES.

ENGINES for pumping need a classification of their own, apart from those for general uses described in the preceding chapter; but though all applied to this one general purpose of raising water, the forms, systems, and methods employed to meet the various cases which occur are of the most diverse kinds. Pumps which may be suitable under certain conditions, may under other circumstances be quite unsuitable; and unnecessary expense or complete failure generally attends the use of pumps so misapplied.

Variety of kind.

Pumps often misapplied.

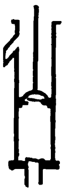
The incidents already described as affecting the choice of a steam-engine, are many of them applicable to steam pumping-engines also, and need not again be enumerated; but there are obviously others which apply particularly to pumping. The quantity of water to be raised in a given time being known, and the height to be lifted, the other circumstances of the case have then to be considered, and these are fully enumerated on pages 629–631. The choice of a pump is often wholly determined by secondary conditions, for the first cost and the power consumed in working may have to be subordinated to the necessity for fixing the pump in a particular place, or the driving it from some existing boiler or steam-engine or running shaft.

See page 591. STEAM-ENGINES.

Choice, how determined.

The various kinds of pumps might from one point of view be classified as Lifting pumps, Forcing pumps, and Pressure pumps, with a separate enumeration of Centrifugal pumps and Rotary pumps. The whole of these may, however, be more conveniently summarised into two groups as Reciprocating pumps and Rotary pumps. Of these two, the first may be subdivided into—

1. The Single-acting pump.
2. The Bucket and plunger pump.
3. The Double-acting pump.



129.

Single-acting pumps.

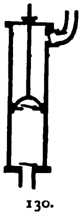
Hand-pumps.

The *Single-acting* pump, as indicated by the term, delivers only on the upward or downward stroke, there being no delivery on the alternate stroke. The simplest form of this pump is the ordinary hand-pump for domestic supplies, raising the water from a well to a spout or trough a few feet above the ground. This is sometimes known as a lifting pump, as the water is drawn or pulled upwards. These pumps have for their characteristic feature the hollow bucket through which the water, after it has been forced up by the atmosphere during the forward stroke, passes as the bucket returns. Commencing with the familiar hand-pump, which can be purchased for £1 and upwards, the sizes increase until the use of steam-power becomes expedient.

Manual v. power pumps.

Examples.

Limit of depth for suction.



130.

Rising main.

Local considerations can alone decide the precise point where manual power should cease, as also the nature of the alternative power to be applied. It may, however, be pointed out that the work of pumping is much too uniform to be efficiently carried on by manual labour for any prolonged period. For pumps worked by manual force the cost will range from £10 for a pump capable of raising with one man 2 gallons 40 feet high per minute, to £25 for one capable of raising 7 gallons 50 feet high with two men. Beyond these capacities, steam or other artificial power becomes necessary, and the cost depends on various circumstances other than the quantity of water and the height. As single-acting pumps are so frequently used for moderate depths, and are generally in such cases fixed on the ground level, it is necessary to remember that, as the vacuum formed by the pump is able to draw only from a depth of 25 feet, the effective part of the pump (the working barrel) must be placed below the ground and within 25 feet of the water when a greater lift is required. If, besides lifting the water to the ordinary level of a discharge spout or pipe on the working barrel (Fig. 129), it is desired to raise the water still higher through a rising main to an elevated tank or reservoir, then the top of the pump must be closed and the joints and other parts of the pump made sufficiently strong and water-tight to resist the pressure of the column of water. There

2-throw cranks.

3-throw pumps.

Horizontal pumps.

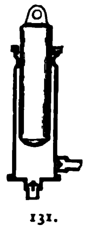
Hot-water pumps.

is an infinite variety of shapes and methods of placing these pumps and of applying the power, and hundreds of engravings would hardly suffice to show the various patterns made by different manufacturers. In some cases it is found expedient to have two such pumps fixed in the well, worked from a two-throw crank at opposite angles, as such an arrangement equalises the work done throughout the revolution of the crank handle. Where three single-acting pumps are worked from one shaft by cranks set at equal angles, they are known as "three-throw pumps." This arrangement, by which a uniform flow of water is obtained, is not only used for pumping water against moderate heads, as in breweries, chemical-works and tanneries, but also for pumping from deep wells and delivering direct into water-supply mains. Three-throw pumps are sometimes arranged horizontally where the suction-water is at a moderate depth. Suction pumps of this class are not suitable for raising hot water, as the steam prevents the formation of a vacuum; and, therefore, for hot water it is usual to employ a force-pump placed below the level of the water to be raised.

Large pumps for short lifts.

Deep pumping stand-pipes.

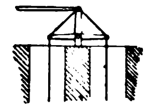
The same principle of single-acting pump is frequently used for raising large quantities of water, as, for example, in pumping out docks, or for drainage, working only under a few feet lift and delivering some tons of water per stroke; and also in pumping out mines or well-sinkings of considerable depth. In the latter case the working-barrel is fixed at a considerable depth from the surface, and the delivery consists of stand-pipes carried right up to the ground or other delivery level, these pipes being of somewhat larger diameter than the working barrel, to allow of the bucket and clack being easily drawn up through the pipe. The pump-rods to which the bucket is attached, work in the stand-pipes, wing-guides being fitted on the rods to prevent their undue vibration. It is difficult to put a limit to the size of these pumps or to the pressure under which they will work.



131.

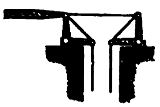
Ram or plunger pumps.

Another usual type of single-acting pump consists of a ram or solid plunger working in an open-topped barrel through a gland, and having an inlet and outlet valve in a box at the bottom of the barrel. The action is similar to that of the single-acting bucket type, except that the delivery water is forced through a stationary valve to the side of the barrel instead of through the moving bucket valve, this arrangement providing for easy access to examine the valves. There is also the difference that the power is applied by the thrust



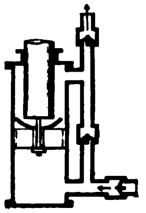
132.

Bell cranks.



133.

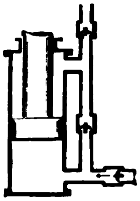
of the pump rod which must therefore, for high lifts, be made stiffer than where the water is lifted by the pull or tension of the rod. For this reason such pumps are sometimes classed among force pumps. Single-acting pumps as above described are sometimes worked direct from a crank on the engine shaft, but more generally through gearing from a bell-crank lever fixed over the head of the well and actuated either by a horizontal or vertical engine. When only one pump is fixed in such a well or shaft it becomes necessary to counterbalance it by weights on the arm of the lever, but when two pumps are used they may be worked from either end of a tee-bob or by coupled bell-cranks (Figs. 132, 133), by either of which arrangements one pump balances the other.



134.

Bucket and plunger pumps.

Mode of working.



135.

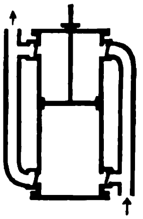
Piston and plunger pump.

Used for public water-supply.

See also page 205.

The "*Bucket and plunger*" pump is an ingenious combination of the two, for though it resembles the single-acting bucket pump (Fig. 129) so far as the valve and bucket are concerned, the pump rod, instead of passing from the bucket directly into the barrel or stand-pipe, is enlarged into a plunger having a fixed relation to the diameter of the working barrel. Assuming that the area of the plunger is just one-half that of the bucket, it will be seen that on the upstroke of the pump the working barrel becomes charged to its full capacity with water, as in the case of the single-acting pump, and that on the down-stroke all the water must pass through the bucket-valve, but that as the plunger, in descending into the barrel, occupies one-half thereof, it forces in this down-stroke half the water up the delivery pipe, the remaining half being delivered on the succeeding up-stroke. The "*Piston and plunger*" pump gives the same result of continuous delivery. The barrel is fully charged at the suction or up-stroke, but only half the water passes into the rising main at the down-stroke, the remainder passing into the working barrel above the piston. At the next up-stroke this also is discharged. In both these classes of pumps the action is that of a single-acting pump on its suction side, while on the delivery side it has the advantage of the double-action pump without the multiplicity of suction and delivery valves. These pumps are largely used for public water-supply. The relative proportion of the plunger area to that of the bucket or piston depends to some extent on the relation of the delivery head to the suction, as, within reasonable limits of uniform water delivery on the up and down stroke, the respective areas of the plunger and bucket may be proportioned to assist in the balancing of the moving parts.

Double-acting Pumps both suck and deliver on the upward and downward stroke, this being effected by having duplicate suction and delivery valves in communication with both sides of the pump piston. By this means, not only on the up-stroke of the pump is the under side of the piston charged with water while that on the top side is being delivered, but on the downward stroke of the piston the operation is reversed, water being sucked in on the top side and forced up on the bottom side. Obviously, for a given delivery of water there is a considerable reduction in the size and weight of the pump-barrel and piston; but, on the other hand, there is the necessity for two suction and delivery valves, which with their valve-chambers add to the cost.



136.

Double-acting pumps.

Steam pumping-engines.

Shafting pumps.

For pumps of considerable size, requiring more than 4 horse-power, a separate steam-engine is generally attached to the pump. Smaller pumps may be worked from shafting driven by a steam-engine or other motor. The latter method is adopted, for instance, in breweries, dye-houses and chemical works for the numerous small pumps which are required at various places, even where the principal pumping is effected by a special steam-engine. While, however, it is convenient to utilise shafting which is already established, for transmitting power to pumps of moderate size, it is seldom expedient to bring power more than 50 feet in this way. Where possible, the pump should be brought nearer to the motive power, and where this is not possible or convenient, the alternative plan should be considered of attaching a steam-engine to the pump and bringing steam from a distant boiler, for there is in such a plan much less loss in transmission than by shafting. Small self-contained gas, oil or hot-air engines are applicable to cases such as these. For underground pumping, when it is difficult to place a primary motor, compressed air or electric transmission is frequently utilised.

Small motors.

See pages 202–212.

Beam pumping-engines.

Non-rotative engines.

Beam pumping-engines may be broadly classed as non-rotative and rotative. Non-rotative pumping-engines for raising water from mines have been almost invariably made as force pumps, with solid plungers or pistons; but those for the supply of towns have often the combined bucket and plunger. In engines of this kind, which have no fly-wheel to store up the energy, the pressure on the piston must be fully maintained for the whole of the stroke, and this was obtainable without undue loss when the atmospheric pressure and low steam pressure were the only forces available. But the modern rotative engine, with steam pressure of 150 lbs. and upwards, and

Rotative beam-engines.

Compared with horizontal engines.

See page 583.

Examples of cost.

Cornish engines.

which, by the use of a fly-wheel, affords a high grade of expansion, has entirely superseded the non-rotative type of engine. For small powers these conditions do not equally apply, as is seen by the development of the steam-pump referred to on another page. The regular and smooth working of the beam-engine is considered by many engineers to render it particularly suitable for continuous pumping for the water supply of towns, the minimum risk of stoppage more than compensating for an increased first cost. As already stated, the extra expense of a beam-engine as compared with a horizontal engine, lies not in the engine itself, but in the extra expense of foundations and buildings. As an example, a beam condensing engine and boilers, for pumping 60,000 gallons of water per hour to a height of 300 feet, would cost in England £5000 to £6000, or about £60 per effective horse-power, and the foundations and buildings about £3000; while a horizontal condensing-engine of similar capacity would cost, with foundations and buildings, about one-third less. When, as is often the case, pumping-engines are erected in duplicate as a reserve against accidents, the difference is of course increased. The continued favour in which the beam pumping-engine has been held so long, is probably owing to the economical working which has been obtained with such engines. The high cost in Cornwall of fuel brought from a distance stimulated all inventions which economised heat; and the introduction of the Cornish boiler and improved beam-engine were keenly appreciated; while on the other hand, in the northern parts of the island the abundance of cheap coal rendered the consumption of fuel a question of less importance, and directed the attention of mine-owners to mere saving in first cost. Therefore, although beam-engines were formerly used in the north, and continue to be used there, they have not been worked so economically as in Cornwall.

Deep-mine pumping.

Difficulties.

The chief difficulties in deep-mine pumping are in the transmitting of power from the engine on the surface to the pump far below; in the enormous weight of the column of water in the rising main; in the packing of the stuffing-boxes of the pump plungers to remain water-tight; and in the maintenance and smooth working of valves and valve-seats under the great pressure. In deep mines it has been customary to divide the total operation into several lifts of practicable dimensions. Thus, one pump is placed at the bottom of the mine to raise the water to a certain height into a reservoir or "sump," from which a second pump raises it to another reservoir, and so on till the surface is reached. By this means the pressure upon the pipes and valves, as determined by the height of each separate rising main, is kept within practicable limits. But the weight of pump-rods to work these pumps is very great, and in mines 1000 ft. deep and upwards the suspended pump-rods will weigh as much as 50 tons. Among the most important improvements in connection with deep-mine pumps have been in the "clacks," valves and valve-seats, and in the material of which they are made. The enormous loads under which the valves have to open and shut subject them to severe shocks, and, notwithstanding all precautions, pumping operations are frequently interrupted by the bursting or breaking of the valves and valve-cases. Various forms of double and treble-beat valves and equilibrium valves have been invented from time to time, which allow large quantities of water to pass at each stroke with but slight lifting of any one valve, and the percussion consequent on the closing of the valves has been reduced to a minimum.

Improved clacks and valves.

Equilibrium valves.

In regard to the expenditure of force for producing certain results, the service performed by a pumping engine is so very evident and, as compared with most of the miscellaneous duties performed by steam-engines, allows of such easy measurement, that any improvements obtained which save power became at once apparent. The number of gallons per minute and the height lifted for a given expenditure of fuel, are the simple factors in the calculation, or if, instead of gallons, pounds of water be taken, then by the customary units of foot-pounds, the service obtained by each horse-power or by each pound of coal, can be conveniently measured. At the time when Watt commenced his improvements, the atmospheric steam-engines then used in the Cornish mines were, at their best, capable of raising 70,000 lbs. of water one foot high for each pound of coal consumed. Not only, however, did the fuel produce a result thus small, if judged by modern standards, but the pumping was limited to a certain depth, because the engines, with a pressure only equal to that of the atmosphere against a vacuum, could not, with any convenient or practicable size of engine, produce a power to overcome more than a certain weight of water and pump-rods. Thus, mining in Cornwall was till Watt's time limited to a moderate depth, and minerals below were all inaccessible. Watt's valuable improvements, by which the effective force obtained from an engine of given dimen-

Pumping service easily measured.

Watt's engines.

In Cornish mines.

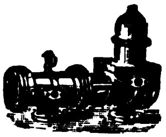
See page 569.

Economy in coal.

Duty of engine per lb. of coal.

Horse-power. *See page* 568.

sions was increased, also allowed a great saving in coal, for his engines proved capable of raising 200,000 lbs. of water one foot high for each pound of coal; or, if judged by the standard of horse-power, was equal to a consumption of 9½ lbs. per effective horse-power per hour. By various improvements in the arrangements of boilers and furnaces, by using steam-engines expansively, and especially by the use of compound engines, the quantity of water raised one foot high, or, as usually stated, the "duty" of the engine, was increased to about 1,000,000 lbs. per pound of coal consumed, or, to state it by the more familiar measure of horse-power, only about 2 lbs. of coal of average English quality are consumed for each effective horse-power per hour, the exact consumption depending, of course, on the quality of the coal. But as steam-pressures have reached and exceeded 150 lbs., even these results have been surpassed. There is no kind of purpose to which the steam-engine is applied which allows such equable results as are obtained from the regular working of a large pumping-engine.



137.

Steam-pumps.

Will work at any speed.

Relation of steam-piston to water-piston.

A valuable addition to the methods previously available for raising water has been made by the invention of direct-acting steam-pumps, of which many thousands have been sold yearly in Europe and America since 1870. The principle of these machines is in their direct action, the pump and steam-cylinder being placed close together in a line upon one bed-plate, the piston-rod from the steam-cylinder being continued into the pump, and attached to the water-piston. The rudimentary difficulty in such a pump is obviously the maintenance—without a fly-wheel and without the elaborate apparatus which is used in a non-rotary beam-engine—of continuous action. This is, however, so completely effected that the engine can be made to move with equal certainty at one or one hundred strokes per minute, as the amount of work may demand. The proportion which the diameter of the steam-piston bears to that of the water-piston depends of course upon the height to which the water is to be lifted, i.e. upon the available pressure on the one hand, and on the weight to be overcome on the other. With a given pressure of steam on a piston of given area, a certain weight can be lifted, and this may either be a short column of great diameter or a high column of small diameter, or, in other words, a great quantity of water for a short height or a small quantity for a great height; and the size and power of a steam-piston may be made of any reasonable proportion necessary to overcome the pressure opposed to it.

Steam pumps convenient.

Direct-acting pumps of this kind are, as is presently described, not economical for large powers where the consumption of fuel is of importance, but they are useful for the numerous purposes of pumping in factories, breweries, chemical works, and other places where the quantity of water to be raised is from 1000 to 10,000 gallons per hour, and the height to be lifted between 20 and 250 ft. For these purposes pumps of some size between 3 in. and 7 in. diameter, with steam-cylinders of from 3 in. to 14 in. diameter, are sufficient, the stroke ranging from 9 in. to 24 in. Steam-pumps of these sizes are, because of their simplicity and compactness, very cheap, and any combination of steam-cylinder and pump within the above limits can be purchased (exclusive of boiler and piping) at some price between £20 and £120. The *quantity* of water which can be pumped in a given time depends on the size of the pump-cylinder and the number of strokes per minute; and manufacturers rate their pumps accordingly. But the *height* to which the water can be raised depends upon the pressure in the steam-cylinder. If there were no loss in working, it is obvious that the steam-pressure would only have to overcome the weight of the column of water. That is to say, in order to raise water 100 ft. high with steam of 45 lbs. per sq. inch pressure, it would suffice if the steam and water pistons were of the same area, because a column of water 100 ft. high weighs 43½ lbs. per square inch, so that for each pound of pressure the water would be raised about 2 ft. But as there must be a loss from friction and other causes it is usual to assume only 1½ ft. of height for each pound of steam if the steam and water pistons are of the same diameter, and on this basis the results which cylinders of different diameters would afford may be also calculated. As an example, a pump with a water-piston and a steam-piston, both of 4 in. diameter, and an effective length or stroke of 12 in., will with 50 strokes per minute propel 3000 gallons per hour. With steam of 40 lbs. pressure, the water would be raised to a height of 60 ft., and with steam of 80 lbs. pressure, 120 ft.; but if a steam-cylinder and piston of 8 in. diameter (which affords an area four times that of 4 in.) were used, the same pump, if maintaining the 50 strokes per minute, would, with 40 lbs. of steam, raise 3000 gallons 240 ft. high. A pressure of not less than 70 lbs. per square inch would probably afford the best results; but as purchasers are not always in-

And cheap.

Power, how calculated.

Examples.

clined to work at such pressure, only 40 lbs. is usually assumed by the manufacturers in calculating the size of pump necessary for a certain service. For situations where a steam-boiler is not already available, and where one has to be obtained, the steam-pump can be purchased with a boiler attached to it, forming when so arranged a complete self-contained pumping-machine, the cost, however, being nearly treble that of the steam-pump alone. In factories where there is no boiler from which steam can be obtained, or lines of running shafts by which power may be given to ordinary pumps, these self-contained steam-pumps are very convenient.

Steam-pumps with boiler attached.

Pumps of this kind are valuable chiefly for their compactness, simplicity and cheapness, but they consume much fuel. This, however, in pumps of moderate size is generally of little consequence, compared with the advantages afforded. For large pumps there must be some other advantage to justify their use. Thus, in a mine, not only do these machines occupy little space, but the steam-pipe does not interfere with the free use of the mine-shaft for other purposes, while with an ordinary mine-pump, the rods and other gear require, in many cases, a separate shaft. Again, in temporary work, where a new mine has to be explored, and where, therefore, the continuance of the pumping is doubtful, the large saving in capital outlay is of great importance. Large steam-pumps up to 14 in. diameter, with steam-cylinders up to 40 in., can be so used, the pumps being placed at the bottom of the mine-shaft, and forcing water to the surface through one rising main. As, however, an ordinary steam-engine utilising steam expansively, and working pumps by means of bell-cranks, would consume only half the fuel, it is only for such temporary service or for exceptional cases that large steam-pumps can be used with advantage. They are sometimes used instead of centrifugal pumps for irrigating, and by contractors for clearing railway-cuttings, foundation-pits, or bridge-pier cylinders of water. In such cases they can be supplied with steam from the boiler of a portable engine. But for pumps of larger capacity and for raising water from deep mines, economy of fuel becomes a matter of the first consideration. The excessive consumption of fuel in ordinary steam-pumps is due to the circumstance that, as there is no fly-wheel to store up energy, the pressure on the steam-piston must always be at its maximum to overcome the resistance of the rising main, for if the steam be cut off before the end of the stroke with a view to expansion, the pump would at once stop. The great waste

Steam-pumps consume much fuel.

Convenient for temporary use.

Large steam pumps.

Where used.

Steam cannot be used expansively.

involved in thus letting the steam exhaust at high pressure has greatly restricted the use of these pumps for raising water from deep mines, or for any case where the service is constant and severe. It has been attempted to minimise the loss by condensing the exhaust, discharging it into the suction of the pump, but this is not always convenient, and even when accomplished only slightly reduces the loss.

Exhaust steam condensed.

Two modifications of the simple pump have been successfully introduced to meet the difficulty, the Worthington and the Davey-differential. In the former, the steam when it enters the cylinder is at a pressure greater than is necessary to propel the water, and the surplus power is applied to compress air in a separate cylinder. The steam being cut off when the piston has advanced only a portion of its stroke, the expanding steam, as it becomes more dilated and unequal to the weight of water against it, is reinforced by the store of compressed air which is released for the purpose. By this means the average force of a varying steam-pressure is made to contain a sufficiently constant power, the compressed air serving in effect the purpose of a fly-wheel, and also by its elasticity saving the pumps from the shocks and concussions which often attend deep pumping. These pumps have found their chief use in the United States.

Expansion of steam utilised.

Worthington pumps.

In the Davey-differential pump there is also a higher pressure of steam at the beginning of the stroke than would be required for forcing forward the pump-piston, but the surplus power is utilised in propelling the pump-piston at 2½ times greater speed, this difference in speed being obtained by connecting the steam piston-rod to the pump-rod by levers suitably proportioned. As the pump-piston advances, the angle of the levers alters, so as to reduce the speed to that of the steam-piston, and the diminished force of the latter owing to the steam having been cut off, is sufficient for the lesser resistance of the pump-piston due to its diminished velocity. By both the systems just described, the great economy due to using steam expansively is obtained both for mine and water-supply pumping. In comparing the two systems, the loss and inconvenience always attending the compression of air have to be encountered in the Worthington pump, as well as the more numerous glands and valves, while in the Davey system some of the saving is, of course, lost by the friction of the intermediate levers.

Davey pumps.

Systems compared.

Pressure-pumps are those which have to overcome some force other than that of the rising main or column of water, and the two

Pressure-pumps, where used.

principal applications of these pumps are for feeding steam-boilers and working hydraulic presses. Generally these pumps are of the single-acting kind described on page 615, with solid plungers. For supplying steam-boilers in the earlier times, when low-pressure steam of from 7 lbs. to 15 lbs. per inch was used, no feed-pumps were necessary, as a tank was easily placed at a height above the boiler sufficient to give a head or weight of water which would enter the boiler against the steam-pressure. Now, however, the pressure to be overcome ranges from 50 lbs. per inch for feeding the boiler of a low-pressure engine to 160 lbs. per inch in a locomotive. Almost all engines are provided with a feed-pump worked by some part of the moving gear, but sometimes the ordinary feed-pump is supplemented or superseded by a *donkey-pump*, or by a steam-injector. This name donkey-pump has been given probably only because of the secondary or subsidiary service rendered, as, except in size, there is nothing peculiar in the principle of such machines. The pumps are made in a variety of shapes and forms, as vertical and horizontal reciprocating engines; and the direct-acting steam-pump just described is also used for the purpose; the one feature aimed at in them all being compactness of size and shape; for while, even in an ordinary engine-room, space is often limited, it is obviously more confined in the engine-room of a steamship, or on the side-frame of a locomotive. A donkey-pump for feeding the boiler of a 10 horse-power engine will cost according to its kind, from £20 to £30, the cost increasing with size, so that for the boilers of a 100 horse-power engine from £30 to £100 is required. A donkey-pump allows water to be supplied to a boiler without working the main engine, which, especially in the case of a steamship or locomotive, is convenient. Donkey-pumps of moderate size can be worked by manual power for the washing of boilers, or to fill or feed them before steam has been raised sufficiently high to perform the service in the ordinary way. For working hydraulic presses, or hydraulic testing-machines, hand-pumps can be used when the service is temporary and seldom required. But for regular work such pumps are driven best by gearing or belting, or by a steam-engine or other motor attached directly to the pumps. There is the marked difference between hydraulic pumps and feed pumps that the former have to overcome great pressures, sometimes exceeding 5000 lbs. to the square inch.

Feed-pumps for boilers.

Donkey-pumps.

See INJECTORS, *page* 628.

Where used.

Cost of donkey-pumps.

Hydraulic pressure-pumps.

See page 766. TESTING-MACHINES.

The pumps described in the preceding pages are all capable of

Low-lift pumps.

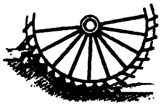
Examples.

Constant or varying lifts.

raising and propelling water against considerable pressure, including, as just stated, what is known as hydraulic pressure. There remain, however, other kinds of pumps useful for low lifts, where the *quantity* of water to be raised in a given time is the primary object in view. The emptying of temporary excavations; the drainage of lakes, swamps, or low-lying land, the irrigation of land, the rapid emptying of docks, and the circulation of sea water through the surface-condensers of marine engines are examples. The value of a pump for any of these purposes depends in each case upon the circumstances under which it has to work, some pumps being best adapted for working against a fixed or constant head of water, while others are the best suited for varying lifts. Such machines come within the category of Rotary pumps referred to on page 626.

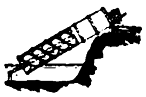
Ancient water-raising machines.

For constant low lifts the old-fashioned *Scoop-wheel* and the *Archimedean screw* have both been largely used for drainage and irrigation purposes, and are still occasionally applied where only animal or wind pressure is available. The scoop-wheel gives its best results for lifts about one-fourth its diameter and with its paddles just immersed. The diameter of the wheel and the arrangement of the blades or scoops should be such that on the suction side the blades may enter the water without undue shock, and that on the delivery side the water shall flow clear away without the blades having any tendency to lift it to a greater height. Unless, therefore, the level of the wheel itself can be altered—as has sometimes been effected—it is obvious that this type of pump cannot adapt itself to any considerable range of level either on the intake or delivery side. For if on the intake the water rises above the blades, the wheel becomes water-logged, and on the delivery side the water cannot clear the blades if it rises more than very slightly above the delivery cill.



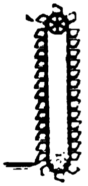
138.
Scoop-wheels.

The *Screw-pump*, which has been applied to the same purposes as the scoop-wheel, allows a wider range of fluctuation on the intake without impairing its efficiency, but the delivery level is under the same condition as the scoop-wheel. The general efficiency of the screw is higher than that of the scoop-wheel, but more costly foundations are necessary for it.



139.
Screw-pumps.

The *Chain-pump* consists of a tube or barrel, round or rectangular in section, and made of cast or wrought iron, and an endless band or chain, generally made of iron links, working continuously up the tube and passing round pulleys at top and bottom. Upon the band are

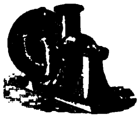


140.
Chain-pumps.

For irrigation.

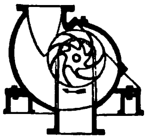
For excavating.

flaps or buckets which lift the water. Though varying in detail, chain-pumps are of two principal kinds—one, in which cups or buckets are attached to the band (as has been used from ancient times for irrigating), and another kind where mere flaps are hinged to the band, against which they lie flat while descending, and project while ascending. These pumps are not often used, but are convenient sometimes for pumping dirty water in excavating operations, or in brick fields, as they will not choke readily. The working barrels and chains are made in about 10-ft. lengths, and can, therefore, by the addition or subtraction of a length, be adjusted to suit an altering depth during excavation. They are generally driven by a belt from a portable steam-engine, but sometimes, especially for irrigating, by oxen or horses.



141.
Centrifugal pumps.

For moderate lifts under varying circumstances the *Centrifugal pump* adapts itself automatically to changes of level better than any other kind of water-lifting machine. It consists of a fan revolving usually on a horizontal spindle at a high speed within a case, in which, when charged with water, a vacuum is created on the intake side and a velocity imparted to the water sufficient to deliver it against the desired head. Different makers claim advantages for different forms of fan and case, but the principle on which they work is mainly the same. At the first introduction of these pumps, about the year 1850, the blades were made straight, but a closer investigation aided by practical experience in their operation has resulted in the adoption of curved blades, bent backwards as regards the direction of revolution. The case is made so as to allow of easy access to the fan, and the suction and delivery pipes, which may be either horizontal or vertical, are easily attached or removed.



142.
Suitable for varying lifts.

Adjustability.

Although, for a definite constant lift, other forms of pump may give a higher efficiency, they do not lend themselves to varying lifts so automatically. As an example, if a centrifugal pump be required to deliver water into a tidal estuary with a minimum lift of 2 ft. and a maximum of 25 ft.—a not uncommon condition—the mean lift is first ascertained and the pump speeded to suit it, the necessary power being provided for a given delivery of water per minute. As the power remains constant, the speed of the pump will adjust itself to the varying head of water, that is, to say, increasing as the height of lift becomes less, and diminishing as the resistance due to a higher lift increases. Their adaptability to varying conditions has led to the substitution of the centrifugal pump for the chain-pump, for con-

Examples of use. **Power and cost.** **Portable pumps.**

tractors' work in clearing excavations of water; but while muddy water may be lifted without damaging the blades of a centrifugal pump, the chain-pump can more safely be applied where gravel, stones or other solid matters are met with. As another example, a small pump with a 6-in. delivery pipe, costing, inclusive of piping, about £30, will raise 500 gallons of water per minute to any height up to 70 ft., and will require $\frac{1}{8}$ horse-power for each foot of lift. A pump with a 6-in. delivery pipe, costing, exclusive of piping, about £120, will lift 3000 gallons per minute, requiring one horse-power for each foot of lift. Pumps of the above sizes are generally driven by a belt from the fly-wheel or pulley of a steam-engine. Portable engines are often used, and in some cases, as for irrigation, the engine and pump are permanently arranged together for this purpose only. Where centrifugal pumps are employed for temporary service, and have to be moved from place to place, they are attached to a light carriage on two or four wheels.

Large centrifugal pumps. **Pumps with horizontal fans.**

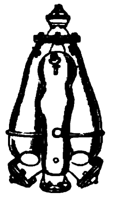
Large pumps are made for special purposes, ranging in size from those with pipes 18 in. diameter, costing about £200, and capable of raising 5000 gallons per minute, requiring about 2 horse-power per foot of lift, to those with pipes 48 in. diameter, costing about £1000, and capable of raising 30,000 gallons per minute, requiring about 12 horse-power per foot of lift. Large pumps for permanent drainage, working with a constant or slightly varying head of water, are sometimes arranged with a vertical spindle and horizontal fan and so fixed in the bottom of a well. The fan being always submerged, the pump is easily started, and for low lifts this is a cheap and convenient arrangement for raising large volumes of water.

Pump and engine combined.

Where pumps of considerable size have to be fixed in a limited space, as sometimes occurs in connection with a tidal dock, or for circulating sea-water through the surface-condensers of an ocean steamship, the pump and its motor are combined as one machine, the shaft of a direct-acting high-speed engine being extended as the pump spindle.

See page 497. **Compressed-air pumps.**

All the pumps that have been described in the preceding pages have some moving mechanism through which the power is applied to the water; but there are other kinds of apparatus by which water is raised without any moving engine. Thus, in the *Liquid-injector* and *Sand-pump* liquid is raised by the direct application of compressed air, and in a diving-bell or caisson the water is driven out in



143

Pulsometer-pump.

a similar way. Steam may be also applied to the raising of water by direct contact. The *Pulsometer-pump* is an ingenious application of an old principle. In this machine there are two chambers fitted with delivery and suction valves, and the steam being admitted to one of them forces up the water which is within it. The steam becoming condensed forms a vacuum, into which the water from below ascends while the upward forcing process is being performed in the second chamber, and thus by a succession of automatic pulsations the pumping continues. As these pulsometer-pumps can be suspended by a chain, and can be easily connected by flexible hose-pipe both for steam-supply and water, they are useful where ordinary pumps have been stopped by being submerged, as well as for other temporary purposes. The prices range from about £12 for a small pulsometer capable of raising 10 gallons of water per minute, to about £50 for one raising about 150 gallons; and so on to about £200 for one raising 1000 gallons per minute, these prices being exclusive of boiler and piping. As these pumps depend upon a vacuum, they cannot lift more than about 25 ft.; but, according to the steam-pressure at command, they will force to a maximum height of about 80 ft. They have also the advantage of pumping thick or dirty water without choking. Machines worked on this principle, though very convenient in some cases, are not to be compared with more usual kinds of pumps under ordinary circumstances, as they consume much more steam in proportion to the work done, and cannot be conveniently applied for any but moderate lifts.

Examples.

Cost and capacity.

Consume much fuel.

Steam-injector.

The *Steam-injector*, which was introduced about the year 1855, adapts and applies certain natural laws by which a jet of steam concentrated in a peculiar way will draw up the water from a reservoir, and force it into a boiler against the steam-pressure there. Injectors find their chief application in locomotives and those other engines where space is very limited, but in many cases engineers, even if an injector be supplied, prefer to have in reserve an ordinary feed-pump. Many modifications and improvements have been made in the steam-injector since its introduction, and the cost has been much reduced, so that an injector suitable for supplying the boiler of a 100 horse-power engine, or that of a full-sized locomotive, costs only from £10 to £15, and the price diminishes to £5 for boilers of 10 horse-power.

Water elevators.

Machines somewhat similar in kind to the injector, but known as *Elevators*, are used for lifting water to a moderate height where there is no other resisting pressure. Such machines find their principal use on locomotives and traction-engines which have to carry a store of water with them, but which have not always access to an elevated tank or water-crane. By merely lowering a flexible hose-pipe into a stream or well, and admitting steam to the apparatus, water may be drawn up as much as 25 ft., according to the steam-pressure at command.

The various kinds of pumps or water-raising machines described in the preceding pages will, with the modifications necessary to particular cases, satisfy all the conditions necessary in pumping. The proper type of pump for the work has first to be selected, and then the method of driving the pump has to be considered. Success or failure may depend on the correct solution of these points.

Choice of pump, how determined.

See page 444.

To enable an engineer to decide upon the kind of pump most suitable for a particular purpose, and upon the size and power for attaining certain results, the following information is necessary; and although many of the points to which attention is directed may appear self-evident, those engineers and manufacturers who have to supply machinery for foreign countries know how frequently the most rudimentary but necessary particulars are omitted from the instructions furnished to them. The particulars already enumerated for steam-engines should be read in conjunction.

See page 592.

Power or capacity.

1. The *Power* or capacity required in a pump depends upon two main points: the number of gallons to be pumped per minute, and the height to which the water is to be raised. These factors multiplied together tell the aggregate number of foot-pounds to be overcome. Thus the same horse-power is required to raise 1000 gallons 100 ft. high in a minute as 2000 gallons 50 ft. high, though for the former the pump must have parts stronger to resist the higher column of water, and for the latter the pump must be double the size; but although this is obvious to engineers, the height to be lifted is not unfrequently omitted by would-be purchasers of pumps as a point of little importance, although not only the power or capacity but the kind of pump depends upon it.

Position.

2. The *Position* of the pump in regard to the source of supply and the place of delivery. The pump is in some cases placed at the level of the source, in others at the level of the delivery, and in others between the two. An engine on the border of a lake, pumping water to a reservoir on a hill; or a pump at the bottom of a mine, raising

Examples.

water to the surface, are examples of the first kind. An ordinary domestic pump, raising water from a well; or a pumping engine on the ground-level raising water from a mine, are the examples of the second kind. A pump on the ground-level, drawing water from a well, and forcing it to a reservoir on a hill, is an example of the third kind. When pumps are to be fixed in a deep well or mine, the engineer, besides being informed of the total depth of the shaft and its diameter, should be made acquainted with the normal water-level, namely, that at which the water stands below the surface, as also the depth to which it may be lowered by pumping, as this may materially affect the arrangement of the pump and its accessibility for repairs. The relative level of the water to be lifted and of the engine-house floor or ground-level are also important circumstances in the design of pumping-machinery. The horizontal distance the water will have to travel is also a circumstance which should be communicated to those concerned; and if the pipes are already made or decided upon, their diameter should be stated, because by the length of the pipes and their diameter will the friction to be overcome be determined. This is very important, as sometimes the friction requires greater power to overcome it than is needed for the lifting of the water. The above particulars may be conveniently given on a plan and section of the site and place of delivery, showing the various levels.

Water-level.

Horizontal distance.

Purpose.

3. The *Purpose* for which the pumping is required—for instance, whether a pump is for irrigation or drainage; or, if for some manufacturing process, the nature of it, as brewing or dyeing; or, if for water-supply, the general conditions which have to be fulfilled; and in any case it should be stated whether the service is to be permanent or temporary, whether intermittent or regular. It is these latter circumstances which generally determine whether cheapness in first cost or economy in working and long endurance are to guide the choice.

Kind of water.

4. The *Kind of water* to be raised—whether clean or dirty, fresh or salt, hard or soft, hot or cold, whether it contains acids or strong chemicals; all these circumstances having weight in determining the form and material of the parts with which the water will come in contact. Tar-pumps, soap-pumps, and pumps for strong acids or alkalis are made.

Space available.

5. The *Space* available for the pump, for the motive-power, and for the suction and delivery-pipes. Pumps have often to be fixed in

inconvenient places, as in mines or tunnels or wells, and the choice of apparatus may have to be guided or modified by some secondary circumstance of this kind, instead of by those which are connected with the primary purpose of pumping. If a well is made or decided on, the nature of the lining—brickwork, masonry or iron cylinders—should be described.

Lining of wells and shafts.

Motive-power.

6. The *Motive-power* which is available or which is to be supplied. If the power is already provided, it should be described as well as the means proposed or suggested for connecting it to the pumps; and if the motor be not contiguous, the means available for transmitting power to the pumps. If a motor is to be supplied, then the kind of force available should be described. If steam from existing boilers, then the pressure and capacity; if new boilers are needed, the kind of fuel available; if wind power, its extent and direction. As wind force is intermittent as a source of power, it is generally necessary to provide for considerable storage of the water raised. If water power is to be utilised, precise particulars should be given as to the quantity of water available for working the motor and the amount of fall, as also whether the head or tail water are liable to flooding. For low falls one of the various forms of water-wheels may be used with advantage. For high falls or in streams liable to flooding, a turbine should be used. If manual force, the strength as compared with English workmen or some other standard; if by oxen or horses, their kind and capacity; if by shafting, its position, diameter and speed. Speaking generally, where the work to be done is of a temporary character, high working expenses may not outweigh the gain of a low first cost, and considerable skill may be exercised in adapting machinery already available. But where the pumping is to be permanent then the machinery selected should be of the highest efficiency, due regard being given to its simplicity and the facility it affords for repairs.

Steam.

Wind.

Water power. *See page 609.*

Shafting.

Buildings and foundations.

7. If *Buildings* or settings of brickwork or masonry are needed, the nature of the soil for foundations, and the kind of building materials which are obtainable and appropriate, should be described.

Fire-extinction.

Among the numerous and various purposes for which pumping-engines of special kinds are required, *Fire-extinction* has an important place, and invention has been stimulated from time to time by the occurence of some great disaster which might have been prevented or mitigated by a prompt supply of water. The apparatus

Depends on water supply.
See page 192.

most suitable must obviously depend upon local circumstances, of which the principal one is the nature of the water-supply. The tendency of municipal bodies to construct or purchase water-works rather than leave them to private enterprise, arises almost as much from this cause as from those connected with the supply of water for general purposes; and even where, as formerly, a monopoly or concession is granted to private persons or joint-stock companies, the sufficiency and suitability of the supply for fire-extinction are among the principal conditions imposed.

See page 200.

Main pressure seldom sufficient.

For fire jet.
See also page 200.

The actual quantity of water abstracted from the public mains for fire-extinction bears so small a proportion to that taken for general purposes (in London $\frac{1}{400}$ part suffices) as to need no consideration in the calculation of the total supply; but it is obviously important that the water shall always be available in sufficient quantity at any one time or place. As one means to this end, there should be such pressure as will cause the water to fill the main pipes at all points in their course, and to rise in a hydrant to, at any rate, such a height above the street level as will supply the tank or suction-hose of a fire-engine; this being generally assured by the more stringent condition that the water—for domestic purposes—shall rise to the top of the highest houses. By the modern system of water-supply in towns such a pressure is provided, but it is much below what is necessary, without the aid of an engine, for fire-extinction. Water in pipes flows to the level of the reservoir or source from whence it is supplied; but though in this way water from a reservoir 100 ft. high will, if unrestrained in its course, rise in time to the top of a house of similar height, it will, if discharged by means of a nozzle on the main as a jet into the air, require a head of water of 180 ft. to enable it, under the most favourable circumstances, to rise 100 ft., or, in other words, the pressure necessary to force water in the air 100 ft. is nearly double that which would take it the same height through a pipe. For lesser heights the proportion is diminished, a 40-ft. head of water sufficing to force a jet about 30 ft. into the air. But where the pipes are also used for general purposes, even this theoretical proportion of jets to head or pressure is generally unattainable, because the continued abstraction of water reduces the effective force or impetuous rising power necessary for a jet. Moreover, the pressure of the water is further diminished by the friction during its passage through the mains and afterwards through the hose which conducts it from the main to the ejection-nozzle, for the pressures just stated are those necessary at the actual orifice of ejection. Approximately, one foot of head, or nearly ½ lb. per square inch of pressure, is required to overcome the friction of every 4 ft. of hose when 150 gallons per minute are being forced; and if, besides horizontal distance, the hose be raised, the vertical distance of course consumes part of the head or force of water, and diminishes that available at the nozzle. The public water-supply mains in many towns, as at Manchester and Liverpool, are supplied from reservoirs high enough for fire-extinction, and the advantage thus gained has been considerable. Where the ordinary public mains are not so available some engineers recommend a separate service of water for fire-extinction only; while by others it is proposed to use the same pipes for the supply of potable water to houses, leaving the water for street-watering, manufacturing and ordinary domestic purposes to a separate service. If a constant high pressure in the fire-mains could be thus assured, it would only then be necessary to place hydrants numerous enough to ensure one being always so near to a fire as to render long lengths of hose unnecessary. The plan of numerous street hydrants has been adopted in the City of London, but only at the low pressure afforded by the New River water company, so that while it affords a ready supply to extinguish a fire speedily, yet except for small conflagrations it is only an adjunct to the fire-engine. The conditions necessary for fire-jets direct from the main are found or adopted so rarely that there are very few towns where fire-engines can be dispensed with, even where the reservoirs are at so great a height as 400 ft. Where hydraulic power mains are laid in the streets, as in London and as in docks and railway stations, the pressure, though too great to be used directly through flexible hose-pipes, may be applied with great advantage for intensifying the force of the low-pressure water in the ordinary town mains, any mean between the two pressures being obtainable by "hydrant injectors" arranged for the purpose.. In London these have been so provided at the National Gallery and other important buildings, but they have not been widely adopted owing to the restrictions of the water-supply companies who control the low-pressure water.

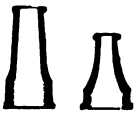
Amount of pressure required.

Separate water service.
See page 202.

Street hydrants.

Hydraulic mains.
See pages 198 & 493.

The effectiveness of a jet depends a good deal on the form and size of ejection-nozzle. It is necessary to concentrate the force of the water at an orifice of small diameter, in order to obtain impetus for a high jet. Even where the water is wanted at low level or for a horizontal discharge, such an impetuous jet has more effect than



144.

Ejection-nozzles.

Nozzles varied.

the same amount of water merely poured or sprinkled on the fire. The orifice, or nozzle, is generally of some diameter between ½ in. and 1 in. for manual-engines, and between 1 in. and 2 in. for steam-engines. The larger sizes allow the greatest amount of water to pass, but a much stronger pressure is necessary to force the jet to the same height as is possible with a nozzle of smaller diameter. But if a very high jet be required, then a larger nozzle is essential, demanding an abundant supply of water at great pressure, because small jets—whatever the pressure—are dissipated into spray at a less height than would a thicker column of water with the same proportionate force behind it. Even in still air no pressure would send a jet $\frac{1}{10}$ in. diameter more than a few feet from the ground, while from a nozzle of 1 in. a jet 100 ft. high could be discharged. It is often necessary during a fire to change the nozzle in order to vary the height of jet.

Fire-engines.

Fire-engines are made of sizes rising by numerous gradations from the small hand-pump to the powerful modern steamer. As an immediate though small supply of water is far more useful in extinguishing a fire than a great supply after the fire is advanced, the smaller pumps are extremely useful, especially in places remote from public fire-engines. Portable pumps of this sort, resembling those for watering gardens, cost from £3 to £7, according to their capacity, which ranges from 5 to 12 gallons per minute to a height of 30 ft.

Portable hand-pumps.

Public fire-engines.

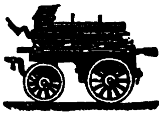
For municipal or public purposes fire-engines on wheel carriages are of course necessary; and such engines are made of various sizes, but there is not much variety in the types which in England have been found to be best, although there are variations in the patterns and details of different manufacturers. The body and wheels are made of wood, painted and varnished, but for hot climates every part is generally made of metal. Engines on two-wheeled carriages, small enough to be drawn by hand, and capable of forcing from 50 to 80 gallons per minute to a height of from 50 to 100 ft., cost from £40 to £80. The exact quantity of water and height of jet depend on the number of men at the pumps, handles for accommodating from six to fifteen men being generally provided. Curricle fire-engines, as these are called, may be advantageously fitted with shafts for one horse, and they can then be increased in size, so as to accommodate 20 men at the pump-handles, a force great enough to eject 100 gallons per minute 100 ft. high—the price ranging from £70 to £100. Even in towns or at fire-stations where powerful engines are available, these small light engines are very useful for putting out

Capacity and cost.

145.
Curricle engines.

small fires, and, if quickly despatched and set to work, will often render the larger engines unnecessary. The employment of these engines for small conflagrations leaves the large engine available at the station for more serious fires.

The pumps and other apparatus of a fire-engine of any but the smallest size are best accommodated on a four-wheeled carriage, and this arrangement is most generally adopted for municipal stations. The pumps are provided with folding handles, which when extended for use can receive and utilise the force of numerous men. The smaller of such engines, costing about £70, will, with from 8 to 10 men, force about 50 gallons 80 ft. high per minute. The larger sizes, costing about £200, such as are used by the London Fire Brigade, will, with 40 to 50 men at the pump-handles, force 200 gallons 150 ft. high per minute, but this height is seldom obtained, as much of the force is lost by friction, according to the length of hose between the pumps and the nozzle.



146.
Engines on 4-wheel carriage.

Number of men required.

Steam fire-engines.

By means of steam fire-engines, a pumping power is concentrated in one engine equal to that of numerous manual engines; a large quantity of water may be discharged so speedily as in many cases to overpower a fire too great for a manual engine; while, if the fire be prolonged, and continuous pumping be required, the steam-engine is not only more serviceable but involves a fraction only of the cost of manual pumping. Five men may be reckoned as equal to one horse-power, and, to equal the effect produced by the consumption of one ton of coal in a steam fire-engine, a concentration of manual engines would be required involving an expenditure for labour (reckoning 1*s.* per hour per man) of £20 or more.

Compared with manual force.

In regard to power, steam fire-engines will, according to their size, discharge from 300 to 1500 gallons of water per minute to a height of from 100 to 200 ft.; and as the maximum height of jet is seldom required, the force is usefully exerted to overcome the friction of great lengths of hose and to supply numerous jets. The hose-friction, which has been already referred to, renders it almost essential, when manual engines are employed, that the water supply shall be near the fire. But a steam-engine will work effectually as far as 800 yards from a fire. In towns or districts where numerous and suitable hydrants are not available, the power of the steam-engine in this respect is of great service, as the supply may be taken from a river, pond or reservoir, at even half a mile distance. As it is convenient to use ordinary hose of moderate diameter, two to four lines of hose,

Quantity and height of jet.

Hose-pipe friction.

each terminating in a jet or nozzle, are necessary to utilise the force of one engine. If the force of the engine has to be concentrated on one jet, the hose and jet must be of large diameter or the hose will burst.

See HOSE, *page* 637.

In the construction of steam fire-engines, the essential conditions are that, with a prescribed weight, which must be moderate to allow of easy draught, there shall be the maximum power, and so applied by suitable pumps as to give out, as measured in quantity and height of jet, a weight of water equivalent as near as may be to the horse-power. The machine employed should be capable of working continuously for many hours without undue heating or friction, and the working parts simple enough to avoid the risk of derangement, even under rough usage. The furnace and boiler should be so constructed as to allow steam to be generated very quickly, and a full working pressure to be maintained without undue exertion to the engine.

See VIGNETTE, *page* 613.

Qualities needed in fire-engine.

Quick in raising steam.

See page 577.

In raising steam from cold water, three-fourths of the time is occupied in bringing the water to the boiling point; and to save time, it is usual at public fire stations, while the engine is not at work, to keep the water in the boiler always hot by having a jet of gas constantly alight in the furnace. When the engine is called on duty, the gas-jet is removed, the wood and coal lighted, and the steam is raised to a working pressure of about 100 lbs. per inch in five minutes, or by the time the engine reaches the fire. But even from cold water this pressure can be attained in about fourteen minutes, and seldom in a less time, if the boiler have sufficient water in it.

Weight and cost of engines.

Steam fire-engines, as made in England, are kept as light as possible by the use of steel and high-class iron, and, being mounted with springs on a four-wheel carriage, can be drawn rapidly by two horses. The smaller sizes, costing about £400 each, weigh about 1½ tons, and the largest size, costing £1500, about 3 tons. When packed for shipment, the measurement tonnage is about five times the weight tonnage, the packing adding 2 to 3 per cent. to the price. An additional expense of £50 and upwards is necessary for suction-pipe and hose, according to the length required. In addition to the various accessories necessary to the working of the fire-engine, and which are included in the prices which have been here stated, there are numerous other articles of equipment, such as hose-pipe, ladders, tools and buckets. About 12 ft. of suction-pipe is included in the ordinary equipment of the engine, but the flexible delivery-hose has to be purchased separately.

Equipment.

Flexible hose-pipe.

Up till about 1880, riveted leather hose was alone deemed strong and durable enough for the rough usage of fire-extinction, but such hose is not only costly to purchase, but is heavy to carry and liable to rapid deterioration unless continually laid out for ventilation and regularly served over with suitable dressing. Improved canvas hose, lined with rubber, is now used in London and other large cities. It is made 2¾ in. diameter, and a much greater length can be carried on the engine or hose-reel than was possible with the 2½ in. leather hose. Canvas rubber-lined hose is made in 50-ft. and 100-ft. lengths, and costs about 2*s.* per foot. The leather hose is, however, deemed preferable for use next to the engine. It is made in 40-ft. lengths, costing from £7 to £9 per 40 ft.

Canvas rubber-lined.

Leather hose.

Hose-reels.

A certain amount of delivery-hose is generally carried on the fire-engine; but sometimes, where the length is great or numerous jets may be required, extra hose must be held in readiness, and therefore separate wheeled carriages are provided for carrying it. The hose-reels, as they are called, cost from £15 for those drawn by hand to £50 for the large carriages for two horses.

Organisation for fire-extinction.

The following particulars are necessary for the elaboration of a scheme of fire-extinction, for the organisation of the men and the choice of apparatus:—

Size of town.

1. The *Area* of the town or district, as shown upon a plan, and the population.

Water-supply.

2. The nature of the *Water-supply*; the abundance or otherwise of water; and, if the supply be from pipes, the pressure which is maintained. The lines of pipes and positions of hydrants should be marked on the plan.

Hydrants.

3. A description of the kind of *Hydrants* or outlets available for fire-extinction.

4. The average and maximum *Height* of the houses.

Kind of houses.

5. The material of the *Houses*—wood, stone or brick—so far as regards inflammability.

Climate.

6. The *Climate*. If dry, whether it increases the inflammability of houses or renders woodwork in the engines inexpedient; if cold, whether the pipes and other apparatus will be exposed to frost.

7. The *Existing means* of fire-extinction; and the experience of the past in regard to fires, so far as it will assist a choice of means for the future.

Control.

8. Under whose *Control* or management the firemen and apparatus will be placed.

Roads and horses.

9. The kind of *Roads* and their gradients, so far as they affect the choice of vehicles, and the motive power.

10. The kind of *Horses* or other draught animals available for dragging the engines.

Floating engines.

If *Floating* fire-engines are wanted, then, in addition to the above particulars, the following also are required:—

11. A *Plan* of the river, dock or harbour where the engine will be used, showing the buildings or shipping to be protected, and limits of width for passing through dock gates.

Depth and flow of water.

12. The strength of *Current* or flow of tide; and the depth of water so far as it may limit the approach of the engine to the shore.

13. The kind of *Water*: salt or fresh, pure or dirty.

Land approaches.

14. Whether there are *Land approaches* by which engines on shore can come to the aid of the floating engines.

Propelling power.

15. Whether *Self-propelling* power is to be applied, or whether the towing by boat or steamer is to be depended on.

Land engines fixed on barge.

Sometimes pumping-engines are fixed on a barge, but unless for use in a dock or other limited area, propelling power is essential to its efficiency. Sometimes a fire-engine is placed on a small steamer which has been made for some other purpose; but there are various advantages in detail which render a special and fully-equipped steamer preferable. Small floating engines, without propelling power, such as are used sometimes in docks, can be obtained for £1000, but the more usual kinds cost from £2000 to £5000.

Cost of floating engines.

Fire apparatus kept in order.

In connection with any apparatus for the extinction of fire, it is essential not only that everything shall be in good order for immediate use, but that those concerned shall be regularly practised in using it. Too often, in places where fires occur seldom, both conditions are wanting, and a fire obtains great way before sufficient water can be brought to bear. Even where the importance of keeping the apparatus is appreciated, the want of readiness in the users limits and sometimes neutralises the advantage. Thus in warehouses, banks and factories, the hydrants, hose, nozzles and buckets are often conspicuously displayed, but as many years may elapse before they are called into service, the hose may be stiff and rotten, the valves too stiff to turn, and unskilled and inexperienced attendants may be unable to connect or use the several appliances. To be of real effect, the apparatus should be regularly practised, and though irregular periods of trial might be best for accustoming the workmen to sudden calls, neglect or discontinuance of practice is best prevented by having fixed

Fire practice.

days, monthly or quarterly, on which the apparatus can be employed for washing the roofs, windows, or walls, or watering the streets, so that those watchmen, foremen or others, who would most likely be called upon for actual service either in the day or night, may know exactly what to do. Ten gallons of water employed immediately will have more effect than 10,000 gallons when the fire is raging.

Cost of fire establishment.

The cost of a fire establishment depends mainly on the completeness and suitability of the water supply and apparatus, on the local peculiarities of the town, houses, and streets, but also to a large extent on the organisation and drill of the men. Only by attention to the latter point can the highest efficiency be obtained from a given expenditure. Exclusive of capital outlay for water-supply, the following was in 1876 approximately the expense in four of the large cities of the world, reckoned per 1000 inhabitants:—London, about £23; Paris, about £50; New York, about £230; Chicago, about £200.

Tanks.

Cast-iron and wrought-iron.

Tanks or cisterns are made of cast-iron, wrought-iron, steel, zinc, slate and wood; but for engineers' purposes, only iron and steel tanks need consideration here. Cast-iron is better suited than wrought iron to withstand rust; its greater substance allows more margin for waste by rust; the pieces of which a cast-iron tank is composed are easy for carriage, and can be cheaply and effectually joined together. Wrought-iron or steel tanks can be made with thinner plates than cast-iron, and are therefore lighter for carriage; they are less liable to sudden fracture; the joints are less obtrusive, and are free from certain objections against flanges and bolts. Small tanks are generally made of wrought iron or steel, as they can be transported whole without damage, but large tanks are seldom made of wrought iron, except where lightness for transport is of great importance, or where there are special circumstances rendering cast iron undesirable.

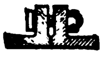
Cast-iron tank plates.

Shape and size.

Cast-iron tanks are made of rectangular plates, generally of some size between 3 ft. and 5 ft., and in thickness between ½ in. and ¾ in. It is generally endeavoured, in designing a tank, to make the plates of uniform size and shape, the dimensions of length, width and depth being, where feasible, of some common divisor. For instance, 4 ft. is a convenient unit for this purpose, the width and length being then 8 ft., 12 ft., 16 ft., 20 ft., or other multiple. Unless for some special purpose other than that of storage, or except superficial space be limited, deep tanks are to be avoided, and the great

Water pressure in tanks.

majority, whatever their cubic capacity, are generally between 3 ft. and 6 ft. deep. As the pressure of water on each square foot of surface is determined, not by the superficial extent of the tank but by the head of water, the strains to be provided against, and the consequent cost and risk of breaking, increase rapidly with the depth of the tank. It is necessary, in all tanks more than about 6 ft. long, to tie the sides together by iron rods placed across the tank, and angle-stays or brackets are inserted to stiffen the vertical sides. Circular tanks, though more expensive and generally less convenient than rectangular tanks, are stronger against internal pressure.



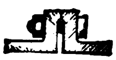
147.

Flanges and bolts.

Outside flanges.

Inside flanges.

Accessibility for caulking and painting.



148.

The plates of cast-iron tanks are fastened together by flanges and bolts, and the question has to be settled in each case whether the flanges shall be inside or outside the tank. The pressure from within the tank tends to tighten inside flanges and to open outside flanges, but tanks should be so strongly made as to render this of no consequence. The smooth, neat appearance of the outside of a tank, when the flanges and bolts are all inside, sometimes leads to the adoption of the latter plan, which in England is that generally adopted for storage tanks at railway stations; but as outside flanges are best, they should be adopted where possible, especially where the purity of the water is of importance. There is the great disadvantage with inside flanges that the bolts are exposed to rust; and the flanges, expecially those on the bottom, hold dirt or sediment, and hinder the easy cleaning of the tank. A smooth, clean surface is sometimes given by a lining of Portland cement flush with the flanges. Tanks are sometimes so situated that flanges outside would be inaccessible for caulking and painting, and where tanks have to be fixed in confined spaces, inside flanges allow the whole space to be utilised, while outside flanges not only project but require room for caulking. Even where the sides can be caulked from the outside, the under side of the tank bottom, where it rests upon its supports, is frequently inaccessible. But outside flanges can, if shaped for the purpose, be also caulked from the inside, and as this is often necessary for the bottom of the tank, some engineers, for the sake of uniformity, caulk outside vertical flanges also from the inside.

Plate edges planed.

In fitting together cast-iron tanks the plates may be so accurately planed at their edges as to need only a smearing of red lead to be water-tight when bolted together; and in such a case the plates should be planed to template so as to be interchangeable. The more usual plan, however, is to fit the edges of the plates with approximate

Iron-cement joints.

Corrosion.

accuracy only, and then to make the joint by caulking between the flanges with cement formed of iron borings. Cast-iron tanks so jointed remain permanently water-tight; but they should be periodically examined to see that the bolts, ties and stays are in good condition. For want of such care cast-iron tanks will fail from corrosion of these parts, and the sudden giving way of the tank. The chances of such accidents are so remote, if moderate care be exercised, as not to outweigh the many advantages of cast iron in the majority of cases; but where a tank is so situated—as, for instance, over a hospital or school—that its failure, and the sudden falling of many tons of water, would cause loss of life, then wrought-iron or steel tanks, which would give more signs of yielding before actual fracture, should be used. But such cases need seldom arise, for where large tanks are elevated, they should be on buildings not used for habitation.

Tanks liable to fracture.

Cast-iron tanks are liable to fracture by great and sudden changes of temperature. Thus, in breweries and dye-works, tanks may have to be filled alternately with hot and cold liquor; and if the change be sudden—and especially if the liquid in entering impinge on one plate—the metal may possibly break. It is therefore generally expedient to employ wrought-iron tanks for such purposes. Sometimes, however, it is convenient for other reasons to use cast iron, as, for instance, in the shallow cooler-tanks of a brewery. In such cases the ordinary iron cement or rust joint is not the most appropriate, and planed joints are the best; but as it is almost impossible to prevent some slight leakage as the tank expands, some absorbent material such as paper should be interposed in addition to the smearing of red lead usual in such joints, as it intercepts the leakage.

Cost of cast-iron tanks.

Cost of fixing.

Cast-iron tanks can generally be purchased at from £7 to £12 per ton above the current rate of pig-iron, these rates allowing for the bolts and stays; but within these limits the exact price will depend on the thickness and weight of the plates, whether they have to be machined, whether the various parts repeat so as to avoid pattern-making, and whether numerous outlets or irregular accessories are needed. The labour in fixing, caulking, and painting a properly-made cast-iron tank costs from £1 10*s.* to £3 per ton.

Weight of water.

Thickness of tank plates.

As each cubic foot holds 6¼ gallons, the size of a tank to contain a given quantity can be easily calculated, and an approximate estimate of weight can be made by assuming a thickness all over of about ¼ in. more than the actual thickness of the plates to allow for the weight of the flanges and ribs. Thus if the plates be ½ in. thick, as in small shallow tanks, then, instead of 20 lbs. per square foot, 28 lbs. would be about the total weight; or, if the plates be ⅝ in. thick, 35 lbs. should be assumed instead of 25 lbs.

Supporting walls and columns.

Tanks are supported either upon brick walls or iron columns, and in either case, if the tank be more than 6 ft. square, a framing of girders should be so arranged as to give bearings not too far apart. Rolled steel joists are convenient and useful as cross supports. It is usual to place the girders immediately below the joints of the plates, this plan being feasible where the caulking is from the inside. Each cubic foot of water weighs 62¼ lbs.

Wrought-iron or steel tanks.

Riveting.

Wrought-iron or steel tanks are made of plates (generally termed sheets when thinner than ¼ in.) from $\frac{1}{12}$ to ⅜ in. thick, according to the size of the tank. The prices of wrought-iron and steel are about the same. For deep tanks steel may be used because of its strength, but iron is sometimes preferred because of a supposed less liability to corrosion. The plates are riveted together like boilers, though with much lighter rivets. The trouble and expense of riveting at the site limit the use of wrought-iron tanks of sizes larger than can be transported whole. Wrought-iron tanks can generally be purchased at rather less prices than those of cast iron, the price per ton being about double, and the weight less than half.

Small tanks transported whole.

Current prices.

Small open cisterns or closed tanks are transported whole, but the limit of size depends, of course, on local circumstances and the means of carriage; but even where possible, the great space occupied is an inconvenience, especially in stowing for sea-carriage, though the space may be utilised by packing other goods inside, or, in the case of open cisterns, by "nesting" together one inside another. The manufacture of wrought-iron tanks has become a special branch of trade, and large quantities are made for storing water on board ship, for holding oil, and for numberless other purposes. From 50 to 500 gallons is the range which includes the small sizes most in demand, and it is customary to state the cost by the capacity, sales by weight seldom taking place, except for larger sizes. The price is not so immediately influenced by the price of raw material as in the case of cast-iron tanks, and when the current price for tank-sheets is from £9 to £12 per ton, the current rates for small open cisterns will range from 7*d.* to 5*d.* per gallon up to a capacity of 300 gallons, diminishing to 4*d.* for tanks holding 600 gallons. If the tanks be covered, an extra cost of about a penny per gallon is incurred. Prices in printed lists are generally

See DISCOUNTS, *page* 435.

much higher than the above, but as in the case of tubes, are subject to discounts. It is usual to coat small tanks with zinc at an extra cost of about 10 per cent., but such coating is not permanent unless itself protected by painting. Large tanks of wrought iron are made of plates varying from $\frac{3}{16}$ to $\frac{3}{8}$ in. thick, and cost from £8 to £12 per ton more than the rates current for tank plates. The largest tanks are those used for the storage of water in towns where no elevated site is available for reservoirs. In such cases very large tanks have to be erected on towers lofty enough to give a head of water sufficient for supplying houses at all parts of the town. As the failure of such tanks would be disastrous, special precautions must be taken to ensure stable supports, and the safety against fracture of the tank itself. Wrought iron is best in such cases, but in order to allow for wasting by rust the plates should be thicker than the load which an ordinary factor of safety requires, and every part in and around the tank and its supports should be accessible for inspection and painting. The cast-iron tank on the elevated tower at the Crystal Palace, London, and the series of wrought-iron tanks in the city of Buenos Aires are notable examples. In each case the tanks are supported on cast-iron columns symmetrically braced. At Buenos Aires there are three tiers of tanks, and the total load supported is, when the tanks are full, about 60,000 tons.

Large tanks.

On lofty towers.

Examples.

See also page 201.

Particulars for designing tanks.

In order properly to design a tank, and to estimate the cost, the following information is necessary:—

Purpose and capacity.

1. Complete *Dimensions of* length, width and depth; or, instead of these, the capacity in gallons, with any limitations in regard to shape, area or depth that may be necessary. Such limitation may often be well indicated by—

Situation.

2. A drawing or description of the *Site* where the tank is to be fixed, showing the height from the ground, the area available and whether it is enclosed or open. The supports should be described, or information given, which will assist a choice between brick walls and iron or steel columns.

3. The *Service* for which the tank is needed; whether for salt or fresh water, hot or cold liquid; the extreme changes of temperature; and whether the tank is to be covered.

Pipes and valves.

4. A description or drawing of any inlets, outlets, *Pipes* and *Valves* that may be needed.

Supports.

5. Whether *Supports* for the tank are to be supplied.

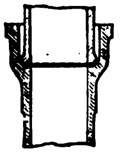
Climate.

6. Extremes of *Climate* and difficulties of transport should be described.

Iron pipes.
See also page 198.

Pipe-founding.

Iron pipes, as used by engineers, may be classed as for water, gas, steam and rain-water; and for all these purposes cast iron is the most usual material; although wrought iron or steel is also employed in certain cases. Pipe-founding, though not a difficult art, requires care and experience to produce sound castings. It is, in regard to its extent, one of the most important of the subsidiary engineering trades; the quantity of pipes made is so great as to render every detail of consequence; and the use of special appliances has brought the cost of pipes lower than that of castings generally.



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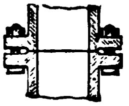
Socket-pipes.



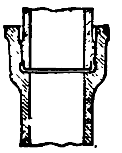
150.

Flange-pipes.

The cylindrical form of a pipe renders it very strong against internal pressure; and the material of cast iron is well suited to withstand the outer pressure or weight which a pipe has to sustain when buried below ground. On the other hand cast iron is heavy for carriage and liable to fracture in shipment. Cast-iron pipes, in regard to form, are of two kinds—spigot-and-faucet pipes, known sometimes as socket-pipes, and flange-pipes: these being the alternative methods of jointing. Flange-pipes, which are held together by bolts, are used for steam and for high-pressure water, and socket-pipes for gas and ordinary water service.

Care in casting.

Must be concentric.



151.

Bored socket and turned spigot.

Where suitable.

In casting pipes, care is necessary, as in other hollow castings, to ensure the core being concentric, for, of course, if the core be misplaced and the section of the pipe eccentric, the pipe is weaker, because thinner at one side than the other. Even if still strong enough to withstand a test, the margin of strength is reduced, though there may be nothing in the outward appearance of the casting to indicate the inequality. In spigot-and-faucet pipes, the diameter of the socket is generally sufficient to allow for trifling inequalities in its shape and in that of the spigot, and to afford also some play in laying or adjusting the pipes in a desired line. But the plan is sometimes preferred of turning the spigot and boring the socket (slightly taper) so that they will fit so accurately as to need only a smearing of white lead or Portland cement, the blue lead or other caulking material usual in loose sockets not then being necessary. Machine processes are so cheaply performed that the cost of turning is more than met by the saving in time and expense in laying the pipes and making the joints. But while this plan may be effective for pipes laid level, and on an unyielding bed, it is not suitable for pipes laid on a less certain foundation; for if the bed yield, there is not the play which the wider socket allows, and the tight turned joint will be more liable to break.

Flange-joints. It is more desirable to make the joint-faces of flange-pipes true by turning; for, though by means of rubber or other washers, or by caulking with cement, a tight joint can be ensured though the metallic faces be slightly uneven, there is more trouble in laying the pipes and more risk of leakage afterwards. And as, if the pipes be not turned, the trouble of chipping the irregularities from the faces (a process not so effectual as that performed by the lathe) has to be incurred, it is always desirable to turn them. **Flanges machine-faced.** The leakage by imperfect jointing may be considerable, and yet in buried pipes so invisible and silent as to be difficult of discovery. **Leaky joints.** *See page* 201. In the water-supply of towns the leakage sometimes bears a considerable proportion to the total consumption, and not only causes a loss of water but a diminution of pressure. In gas undertakings, also, the loss by leakage sometimes equals or exceeds the amount necessary for profit on the capital expenditure. *See page* 251. GAS MAINS.

Mode of casting. The foundry moulds for very small pipes are laid horizontally. For the larger sizes, a slanting position was formerly adopted; but it may now be considered as obsolete, and a vertical position is generally demanded by engineers for pipes over 3 in. diameter; **Vertical moulds.** for cores of larger diameter are, unless placed vertically, liable to float or rise upwards in the mould, and make the upper side of the pipe too thin. **Advantages.** Moreover, when soundness and closeness of texture in any part of a casting is required, it is an ordinary incident of the founder's art to place that part downwards, because the weight of molten metal compresses that at the bottom, and the air-bubbles and loose sand that may have fallen into the mould rise to the upper part. When pipes are cast vertically, the weight and volume of iron in the runners or conduits through which the molten iron enters the mould are not always sufficient to secure solidity and purity of metal throughout the body of the pipe, though it is generally considered sufficient for this purpose in ordinary castings; and therefore it has become the practice among the best pipe-founders to cast the socket downwards, **Sockets cast downwards.** and to allow a considerable head of metal (chiefly by a prolongation of the spigot end), which is afterwards cut off in a lathe.

The proper strength and durability of cast-iron pipes are assured—

Strength and durability, how ensured. 1. By giving that *Thickness* to the pipes which calculation, based on an assumed tenacity of the metal, shows to be necessary to the diameter of the pipe and the pressure to be endured. To allow for inequalities in casting, safety in carriage and wasting by rust, water-pipes are generally designed with a factor of safety, which, if calculated **Factor of safety.**

according to the internal pressure they are to endure in working, ranges from 6 to 1 to 10 to 1, according to the purpose to be fulfilled and the opinion of the engineer. For situations where the pipes will not be exposed to rough treatment, a factor of 6 to 1 may be sufficient; or 8 to 1 if for water mains in towns; while in cities where there is heavy road traffic, 10 to 1 is often adopted.

Quality of iron.

2. By using *Good Iron.* The quality of the iron, though often specified, is seldom, except in large or important contracts, really ensured by supervision and tests, and inferior metal may then be used without detection, because it may be amply sufficient to bear the water-pressure test. Iron re-melted from pig-iron in a foundry should be specified (to the exclusion of iron cast from a blast-furnace), and of a strength which will bear on the standard test-bar, already described, a certain load. A weight of 25 cwt. should be the minimum, but this only shuts out very inferior iron, and 28 cwt. may be obtained without difficulty. If a minimum weight of pipe, or great tenacity of the metal is important, as, for instance, for long transport, or to endure rough treatment, 30 cwt. is specified, and for this the iron in some districts is, if used alone, not strong enough, but may be made so by the admixture of superior iron. If it were not for the inconvenience of constant supervision, it would always be advisable to use good iron, as the advantages obtained outweigh the extra cost. A greater test load than 30 cwt., though occasionally demanded for special purposes, is not expedient generally.

Test-bars. *See page* 541.

Supervision.

Mode of casting.

3. By proper *Methods of Casting.* Although an engineer will generally specify a vertical position for the mould, yet, as the plant and appliances of pipe-founders differ, it may be necessary to verify by inspection before and during manufacture that the specification is obeyed.

Thickness verified.

Tolerance allowed.

4. By verifying the thickness of metal by *Weighing* each pipe. A margin—generally of about 4 per cent. for small pipes of 3 in. diameter, and diminishing to 2 per cent. for pipes of 36 in. diameter—is generally allowed, within which limits any pipe otherwise good will be received; but sometimes it is stipulated that no excess of weight beyond 1 per cent. will be paid for, as it may be expected that the average difference will not exceed this.

Gauging and measuring.

5. By *Examining* each pipe inside and out, to see if there are any unsound places; and by gauging and measuring to prove that they are concentric in section, and that the spigots, sockets or flanges are

of proper form and diameter. A disc $\frac{1}{8}$ in. less in diameter than the prescribed bore of the pipe should pass freely inside.

Testing of pipes by water.

6. By *Testing* each pipe by high-pressure water, to detect flaws or cracks in the metal. A pressure equal to a column of water 300 ft. high (about 130 lbs. to the square inch) is generally adopted as sufficient for this purpose, and this rule is in Great Britain so well established, as to be almost an assumed condition in bargains for pipes, and every pipe-founder has testing machines as part of his ordinary apparatus. But for thick pipes, in which the working pressure will exceed 200 ft., a greater test-pressure is prescribed, rising to 1000 ft. where the working pressure exceeds 500 ft. The above tests do not prove the strength of sound and well-made pipes, but are enough to ensure that—within the short time the pipe is under pressure—the water shall penetrate to and discover cracks, flaws or spongy places. Still further to detect weakness or liability to fracture at such unsound places, it is usual while the pipes are under pressure to rap them with a hammer. The cast-iron pipes for the London hydraulic mains (averaging 7 in. diameter) are tested to 2500 lbs.

Usual test-pressure.

Coating of pipes to prevent corrosion.

7. By *Coating* the pipes inside and out with some preservative compound. Corrosion is specially damaging to pipes, for it not only wastes away the metal but the rust accumulates, and, fungus-like, expands (the composition of the water often assisting this) so as to choke the passage-way. So serious are such consequences that many plans of coating and painting have been devised to prevent it. The pipes should be oiled directly they have been trimmed in the foundry, before rust has commenced, and then coated. The most successful coating is that known as Dr. R. A. Smith's process, by which the pipes are coated inside and out, while hot from the foundry mould, with a peculiar bituminous composition. This plan, which adds from 2*s.* 6*d.* to 5*s.* per ton to the cost of the pipes, is almost invariably adopted for water-pipes, and postpones greatly the decay of the iron. The durability of the coating depends on the efficiency with which it is performed and on the kind of water passing through the pipe. In some cases the coating shows no signs of deterioration after twenty years' use.

Cost.

Pipe inspectors.

Precautions such as these demand care and knowledge, and inspectors who have had special experience are generally employed. But notwithstanding the care which may be exercised during and after manufacture, it is seldom that a certain proportion of faulty pipes can be avoided, and if such pipes are buried *in situ*, without their faults

Pipes tested *in situ*.

being detected, they may be the cause of much loss by leakage—often silent and undiscovered—or of expense in substituting new pipes. It is important, therefore, that a line of pipes while being laid, and before the trenches are covered up, should be tested under pressure; convenient lengths of pipe being temporarily isolated and closed for the purpose, a process by which also, in gas-pipes as well as in water-pipes, the condition of the joints may be ascertained.

Evils of leakage. *See page* 251.

The loss of gas by leakage is often very great, and the saturation of the soil in large towns from this cause is an important sanitary question.

Pipes sold by weight.

Cast-iron pipes are generally sold by weight, and the total cost depends on the thickness of the metal; the cost of carriage being also so determined. A bargain for pipes at a price per ton is therefore incomplete unless accompanied by a statement of weight, which may be specified either by the purchaser or the seller. The weight depends mainly on the thickness, but a little also on the dimensions and form of the socket or flange. In some cases, purchasers who have specified the thickness or weight of pipes, and the water-pressure test to be endured, make no other stipulation in regard to the quality of the iron; and, for small quantities or unimportant purposes, the expense of further precaution may be inexpedient, and a proper quality ensured by dealing only with manufacturers of good repute and who use iron of known quality. But in important cases, a certain tenacity in the metal, as measured by the weight sustained by a test-bar, is as already stated, also demanded.

Standard weights.

Every pipe-founder has his own standard weights, to which, either exactly or within moderate limits, he is prepared to adhere; but when a rate per ton is the measure of price, a water-pressure test the measure of quality, and no conditions as to thickness, weight or tenacity demanded, there is no inducement to the founder to save in weight by using iron of high quality and taking due care in manufacfacture; and pipes so bought will presumably weigh more than pipes bought with prescribed limits in these respects.

Limits of weight.

But bargains are seldom made without limits of weight, and pipe-founders are generally prepared to conform to usual limits, although, of course, the less the weight the less will be the remuneration which a given price per ton will afford for the labour of making. But even iron of the lowest quality will, as already stated, if cast without flaws, endure the water-pressure test, so that it alone is but a partial protection. Therefore, in comparing competitive offers from manufacturers, the lowest price per ton, even if allied with moderate weights and subjection to the ordinary water-test, is not necessarily the cheapest, unless the quality of the iron and the consequent margin of safety and non-liability to breakage be taken into account, as well also as the soundness and concentricity of the castings. In gas-pipes, and frequently also in water-pipes, the working pressure is so small as to need no consideration in deciding on the thickness of the metal, which has to be determined by other circumstances, such as the substance necessary to ensure soundness in founding, safety in carriage, resistance to external pressure when laid, and endurance against rust. In the case of long carriage or frequent transhipment, breakages are sometimes very numerous, and it is important to provide, either by special insurance or by specific contract with the carriers, for the loss by breakage. Shipowners and others sometimes seek, by special clauses in their bills-of-lading or carriage-contracts, to avoid their ordinary common-law obligations in this respect.

Lowest price not always cheapest.

Breakages during carriage.

See page 447.

Usual lengths of pipes.

Cast-iron pipes are, in England, made 9 ft. long, when the diameter does not exceed 12 in.; beyond this and up to 48 in. a length of 12 ft. is usual; the length in each case being that which is net or effective when laid, exclusive therefore of the socket.

Table of weights.

Spigot-and-faucet pipes, if cast with care from good iron capable of enduring 28 cwt. on the standard test-bar, do not require for a working pressure of 80 lbs. per square inch, and a factor of safety of 10, a greater thickness than the weights in column A imply, and many engineers consider these the minimum weights even for lower working pressures. For convenient comparison all the lengths are stated as 9 ft., but an addition of one-third will give the weight of 12-ft. lengths. The weights in column B are sufficient for a working pressure of 160 lbs. But, in the absence of stipulation to the contrary, pipes weighing from 5 to 20 per cent. more are generally supplied by manufacturers, and, unless careful and constant inspection can be insured, it is inexpedient to demand the minimum

Diameter of bore.	Net Length.	Weight each in lbs.	
		A	B
3 in.	9 ft.	108	136
4	9	152	200
5	9	202	275
6	9	256	360
7	9	316	454
8	9	380	562
9	9	450	680
10	9	530	806
12	9	690	1092
14	9	876	1420
16	9	1082	1790
18	9	1309	2200

weights given above. Flange-pipes, if of the same thickness as spigot-pipes, weigh from five to ten per cent. more, but they are usually made thicker than socket-pipes, as there is more difficulty in casting (the upper flange forming a lodgment for the impurities in the metal), and therefore some allowance must be made if the flange-pipes are to be as strong as the socket-pipes. The thickest pipes are those—always with flanges—used for the rising mains of deep mine-pumps, which have to withstand an enormous pressure, and those with diameters seldom exceeding 8 inches used for hydraulic mains.

Thick pipes. *See pages* 619 *&* 493.

Prices fluctuate with value of iron.

As pipes come within the category of cheap castings, the cost of manufacture bearing a less than usual proportion to the value of the metal, prices follow closely the current rates for pig-iron. Socket (spigot-and-faucet) pipes, which are the kind generally assumed by the manufacturer, in the absence of stipulation as to kind or purpose, cost, for all diameters above 5 in., £3 to £4 per ton above the current price of pig-iron; the price of pig-iron ranging in ordinary times from £2 to £2 10*s.* per ton. The exact prices of pipes are determined by the quantity ordered at the same time, the severity of the tests, and the conditions of delivery and payment. If the sockets and spigots of the pipes have to be bored and turned, an extra rate of from 7*s.* to 15*s.* per ton is incurred. From 3*s.* to 6*s.* per ton is the extra cost for coating with a preservative process. Flange-pipes cost about £2 per ton more than socket-pipes, but the extra expense of turning is about the same. As the low prices at which pipes are sold is owing to the great repetition in manufacture, small or miscellaneoüs quantities are much dearer. Branch pipes, tees, bends and other pipes classed as irregular, generally cost from £4 to £5 per ton more than the current price for ordinary straight pipes, and if—as in connection with a pumping-engine or steam-boiler—pipes of various sizes or lengths be required, the ordinary prices are no longer applicable, the special economies of manufacture become impossible, and, as in other classes of foundry work, the price is determined by the cost of patterns and other preparations.

Range of price.

Extra charges.

Irregular shapes dearer.

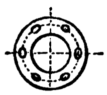
Pipes made to gauge and interchangeable.

Pipes should be made so exactly to a pattern or gauge as to be interchangeable; and for permanent undertakings where renewals or extensions are likely to occur, as in the case of municipal gas and water works, standard patterns should be established. Pipes made without such rules, even if of the same nominal size, if bought at different times from different manufacturers, involve extra trouble and expense in the laying and in the making of joints. In flange-pipes not only should flanges of a uniform diameter and thickness for each diameter of pipe be prescribed, but it is important also that the position of the bolt-holes should be uniform. In pipes subjected to great pressure of steam or water, the flanges are often cast without bolt-holes, these being afterwards drilled with great exactitude, and the bolts turned to fit. But in the majority of cases, the cheaper plan of making the holes in the process of casting is adopted. Besides making the hole larger than the bolt, an additional margin for adjustment is provided by making elongated or oval holes. Templates or patterns for the flange and bolt-holes should be provided for each size of pipes, and in the case of bends and other irregular shapes, the relation which the horizontal axis or other datum-line bears to the setting-out of the holes should be indicated.

Holes in flanges.

Drilled holes.

Cast holes.



152.

Particulars for designing pipes.

In the absence of a detailed drawing or specification, all or some of the following information (as the nature of the case indicates) should be furnished to the manufacturer, to enable him to make pipes of suitable kind and to estimate the cost.

Size or capacity.

1. The *Diameter* or bore of the pipes, or if this cannot be given, the quantity of water or gas to pass in a minute with a given pressure.

Quantity and kind.

2. The *Number* of pipes required, or the total length in lineal feet; and whether flange or socket joints.

Purpose.

3. The *Purpose* for which the pipes are required. If for steam or water, the maximum working-pressure.

Pattern.

4. If the pipes are to connect with others already fixed, or where some standard pattern is established, a *Drawing or Template* of the socket, or of the flanges and bolt-holes, will be necessary to ensure uniformity.

Bends and tees.

5. The number and description of *Bends*, tees and other irregular forms.

Joints.

6. Whether the *Joints* of the pipes are to be turned or bored.

Painting.

7. Whether and how the pipes are to be *Coated* or painted.

Tests.

8. The *Tests* to which the pipes are to be subjected.

Rain-water pipes.

Rain-water pipes are made almost as thin as the process of casting will allow, and therefore such pipes are peculiarly liable to fracture during carriage. When, however, they are fixed in place the pipes are strong enough for their purpose, and if kept painted will probably last as long as the building to which they are attached; but if too thin or not cast concentric, or if not regularly painted, the iron will

Sold by measure.
Irregular shapes.

soon waste by corrosion and the pipes be rendered useless. Rain-water pipes have socket joints and are sold by measure of length, and not weight. In specifying such pipes the bends, swan-necks (almost always needed to clear projections on buildings) and enlarged head-castings which are required should be described.

Wrought-iron and steel pipes.
Where used.

Wrought-iron or Steel pipes (as distinct from tubes) are made of plates of all thicknesses from $\frac{1}{20}$ in. to $\frac{1}{4}$ in., bent into form and then riveted or welded. In Great Britain the use of such pipes was, until mild steel became available at a low price, confined to such minor purposes as chimneys in smithies, or for conveying the blast to smithy fires or compressed air in mines, or as water-pipes for chain pumps, or in well-sinking operations, as they are light for handling, and bear, with little risk of breakage, constant movement and adjustment.

For gas and water.
Pipe lines.

For more important purposes, such as the conveyance of water, gas or steam, cast-iron pipes are, for countries where they can be cheaply made, generally preferred as being cheap and easy to make, strong not only against internal pressure, but also against crushing when laid underground. In many foreign countries where the sea and land carriage are costly the conditions are different, and the lighter and less fragile pipes made of wrought iron or steel are the cheapest. They are used as main pipes for public gas or water supply, for conveying water or compressed air in and about mines, and for conveying water long distances for irrigation or for hydraulic mining. They are also used as "pipe lines" for transporting oil or natural gas.

Steel and iron compared.
Saving in weight.
Riveted pipes.

Wrought iron and rolled steel of the kinds used for pipes differ little in price; they each by their tensile strength afford ample resistance to internal pressure, and though less strong than cast iron to withstand an outside crushing force, they will flatten rather than break, an advantage under many of the circumstances in which pipes have to be handled, carried and laid. When on these almost equal terms wrought iron is preferred to steel, it is usually because of its supposed less liability to rust and supposed greater safety in welding. As riveted or welded pipes are less than one-third the weight of cast iron of equal strength and capacity, the cost is generally less when long carriage by land or sea has to be paid for. Riveted pipes are made of all diameters from 8 in. upwards, and although diameters exceeding 3 ft. are seldom required they are occasionally —as for conveying large volumes of water with little or no head or pressure—made up to 10 ft. diameter. For well-sinking, or for purposes where the pipes have to be frequently handled or changed, the riveted pipes are usually made in lengths of about 10 ft., but for permanent work and where no difficulties in carriage and stowage arise they can be made of any length up to 25 ft. For sea carriage single pipes incur heavy freight by measurement tonnage, and it is desirable therefore to arrange for different diameters to be shipped at the same time so that the small pipes can be "nested" in the larger ones, a difference in diameter of 2 in. or 3 in. being necessary for this purpose. Where this is not possible, a saving in freight is sometimes attained by leaving the riveting of some of the pipes, say of one-half or one-third of the total number required, to be done after arrival; these pipes, after having been formed and punched for the rivets, being stretched open for the nesting of one or two pipes within. Riveted pipes generally cost about double the price current for the plates or sheets of which they are made. The lengths of pipe are jointed by simple forms of socket and spigot or by flanges, the latter method being necessary for high pressures. Projecting rivet heads and lapped joints are sometimes objected to as obstructing the flow of water and increasing the opportunities for incrustation or deposit. To meet such cases, the pipes can be welded with a flush surface inside and outside, special machine processes being available for this purpose, the heating being effected either by an electric current or gas jets.

Usual lengths for well-sinking.

Tonnage measurement.

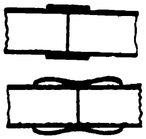
See page 445.

Nesting of pipes.

Rivets omitted.

Mode of jointing.

Wrought-iron pipes may be jointed by enclosing the ends in a short piece of pipe of larger diameter, and caulking the annular space with lead. This plan only suffices for very low pressures of water or gas. What is known as the "Kimberley joint" affords a stronger junction, as internal pressure tightens the pipes against the caulking material.



153 and 154.
Kimberley joint.

In France, wrought-iron pipes of a peculiar kind are made, and have been largely used on the Continent for mains in the streets, not only for conveying gas, but also for water of moderate pressure. The pipes are made of sheet iron coated on both sides with lead (*terne-plates*), and the seams after being riveted are soldered. The pipes are then covered outside with a thick coating of bitumen. These pipes are light for carriage, will withstand considerable internal pressure, will bend rather than break, and are durable against corrosion. They are not, however, so strong against outside pressure and the shocks of street traffic as cast iron, and will not withstand high internal pressure. These composite pipes are made in

Pipes coated with lead.

Coated with bitumen.

lengths of 4 metres, and, one end being slightly distended to form a socket, a joint is made by driving with a mallet the end of another pipe into it, the latter having the bitumen partly cut away and a groove left for a ring of hemp and tallow. The pipes are sold by measure of length, and cost in France rather more than cast-iron pipes cost in England; but they are light for carriage, and are cheaper in many parts of the Continent than cast-iron pipes made in a local foundry or brought from a distance. Pipes of a somewhat similar kind, lined inside with asphalt, have been used in Australia and elsewhere.

Lined with asphalte.

Tubes.

How used.

Tubes are made of iron, steel, copper or brass, and by engineers are used principally for multitubular boilers, as the component parts of tubulous boilers and bicycles, as refrigerating tubes in surface condensers, and as pipes for conveying steam, water and gas. Iron and steel tubes are made by bending strips of these metals into the desired form and welding the edges either by a lapping joint or by a butting joint. Since 1880 weldless steel tubes have been made in increasing quantities, especially for diameters exceeding 2 inches.

How made.

Iron tubes strong against pressure.

The small diameter of tubes render them very strong against either external or internal pressure—even a moderate thickness of metal having a tenacity great in comparison to the strains which, under ordinary treatment, the small surface area exposed can bring upon it. Indeed, the thickness of tubes is often much in excess of what the pressure would require, and is determined by secondary reasons. Thus, in tubes used for conveying steam, gas or water, the connections are generally made by screw sockets or couplings, and, as the screw-thread is cut into the metal, the latter must be thick and strong enough to allow for such a diminution of substance. But for tubes used in boilers and surface condensers, it is important that the metal shall be as thin as possible, so as to transmit heat readily; and as such tubes do not require a thread cut into them, they can be made of the minimum thickness which, with a proper margin of safety, the strains upon them require. But being thus made thin, there is not sufficient contact surface on the edges to allow an effective butt-weld, and such tubes—if of iron or steel—are lap-welded, while the thicker tubes with screwed ends may be butt-welded, which costs less than lap-welding, but is not generally considered so secure. The ordinary iron tubes sold by makers of repute without any special stipulation as to quality, and used principally as

Thickness.

Connections.

Lap welds.

Butt welds.

Gas-tubes.

gas-pipes, are strong enough also for steam or water with a working pressure of 10 to 20 lbs. to the inch. But as the failure of tubes arises from flaws in the iron or imperfect welding, which are revealed even by moderate pressure, and as, if there be no such defects, the iron is thick and strong enough to withstand considerable strains, it will generally be found that the tubes which will endure 20 lbs. pressure will endure much more; but for higher working pressures than 20 lbs. it is expedient to state the purpose and to stipulate for tubes of guaranteed strength. Thus, for iron tubes used in the boilers of locomotives, an internal pressure of 800 lbs. and an external pressure of 250 lbs. are sometimes specified as tests to be endured without fracture. The thickness of the tubes has to be increased according to the diameter, and even of the same diameter different thicknesses are made, according to the purpose in view.

Strength against bursting.

Test pressures.

Large lap-welded tubes.

Extra strong lap-welded tubes up to about 6 in. diameter are made for use as "pipe lines" for conveying oil. In this case the thickness of the tubes must accord with the hydraulic head or pressure, which varies with the contour of the country along which the tubes are laid. These lines of pipes are sometimes 100 miles long, and it is usual to arrange them in sections of 10 or 20 miles, with occasional relief valves and outlets. Still stronger tubes are used for well-sinking, where they have to be forced or screwed into the ground or inserted as revolving shafts with the diamond drill. The strongest tubes of all are those made specially for conveying water for hydraulic machines, the working pressure for such purposes ranging from 500 lbs. to 8000 lbs. per square inch.

Long pipe lines.

Tubes for diamond drill. *See page* 823.

Steel tubes.

Steel has not superseded iron for welded tubes to the same great extent as in some other kinds of engineering material. This is partly due to the superiority of iron for safe welding, to its greater endurance against extreme heat and changes of heat, as in boilers or against rust, and even more to the fact that little saving is to be obtained by reduced weight. The advantages afforded by steel become more apparent even in the welded tubes where a diameter of 2 in. is exceeded, while for weldless tubes steel alone affords the necessary ductility for the process by which they are made. A steel ingot of cylindrical shape, having a hole cast or drilled in it, is elongated and made thinner by a succession of passes through powerful rollers, which squeeze the metal against the mandril on which the operation takes place.

Weldless tubes, how made.

A great impetus has been given to the manufacture of steel tubes

Bicycle tubes.

Tubulous boilers.

Artesian well tubes.

Telegraph poles.

See page 86.

by their use in the framework of bicycles for diameters between ¾ in. and 2 in., and where lightness combined with strength is a primary consideration, and also as the component parts of tubulous boilers. For this latter purpose tubes of diameters ranging from 1 in. to 2 in. are usual in boilers of the Belleville type, and those with diameters of 6 in. to 10 in. for land boilers. Weldless tubes are also used for artesian wells, the tubes being inserted either by blows from a falling weight, or, as in the case of the diamond drill, by using them as revolving shafts. Long lap-welded iron tubes made taper are used as poles for supporting electric conductors.

Failure of tubes.

Well-made tubes seldom burst from internal pressure unless they are weakened by corrosion, but tubes badly welded, or made of inferior material, will sometimes tear open, especially under great pressure. Tubes of inferior iron have often minute surface cracks, which develop under heat or pressure and tear open. Boiler-tubes are the kind most liable to failure; their durability is in any case limited by the severe service they perform, and if of inferior quality, or if not renewed in time, they will fail by bursting, burning, or by tearing from the plates which hold them.

Tubes for multitubular boilers.

See page 574.

Gauges.

See page 551.

Brass and copper tubes.

Solid drawn tubes.

Alloys.

Iron tubes are of the kind generally employed for multitubular marine boilers of the Scotch type, though brass tubes are used for such boilers in the Royal Navy. These brass tubes range from 2½ in. to 4 in. external diameter, and the thickness from No. 7 to No. 11 Imperial Standard gauge. Brass and copper tubes are either rolled by machinery and the edges brazed together, or they are drawn in such a way as to be seamless. The latter plan, formerly very expensive, has been cheapened, and the tubes so made tend to supersede the brazed tubes. From ¾ in. to 5 in. external diameter are the usual limits of size for brazed tubes, and beyond these sizes they are made by coppersmiths, and not by tube-makers. Solid drawn copper tubes are made up to 9 in. diameter. Solid drawn brass tubes are made of all sizes between ½ in. and 4 in. external diameter. The quality of brass tubes depends not only on the manufacture, but on the alloy of the brass. Different alloys are used for different purposes, but from 67 to 70 parts of copper to 30 to 33 parts of zinc embrace almost all the combinations; but these metals must be pure to make good brass.

The occasional failure, under disastrous circumstances, of the brazed joints of large copper pipes in marine engines has led to the use in certain cases of homogeneous pipes made of copper electro

Electro-deposited copper tubes.

deposited by the Elmore process on a revolving mandril, the copper being compressed and strengthened by a rubbing tool as it is deposited. This plan is only available for pipes of simple cylindrical form.

Usual lengths of tubes.

Prices.

Fluctuations arranged by percentages. *See page* 436.

Tubes coated inside.

See page 552. S.W.G.

Tubes are usually made in lengths of from 14 ft. to 16 ft., and are sold by lineal measure. The prices for ordinary iron tubes range from about 2*d.* per foot for ½ in. internal diameter to 4*d.* per foot for 1 in. diameter, 10*d.* for 2 in., increasing to about 3*s.* 6*d.* for 4 in. diameter, and 9*s.* for 10 in. diameter. But the great majority of tubes sold are less than 4 in. diameter, and the larger sizes are used for the various special purposes named above. The prices of tubes being stated according to so small a measure of quantity as one foot, ordinary money units of pence and farthings are insufficient to express small gradations or fluctuations in price, and it is the custom of the trade in England to adjust prices by percentages. Instead, therefore of altering price-lists from time to time, printed lists are established which remain in force for years, the actual price at any particular time being arrived at by deducting the discount which is then current. The printed prices were (1897–8) about double those stated above, but are subject to discounts which during the twenty years ending 1897 have ranged from 20 per cent. to 75 per cent. according to circumstances. Iron or steel tubes may by a special process be coated inside with enamel, but as this about doubles the cost, the expense is seldom incurred except when the tubes are used for conveying corrosive liquids. Tubes may be coated with a bituminous mixture inside and out for an extra cost of about 3 per cent., or galvanised for about 10 per cent. Small copper tubes of about ¾ in. external diameter and about 18 S.W.G. thick, as used for surface-condensers, and larger sizes, as used for refrigerators in breweries, are sometimes tinned inside.

Screwed ends.

Fixing of boiler tubes.

Each length of tube—if for gas, water, or steam—is screwed at each end; this, with the supply of one connecting-socket, being included in the price per foot. Boiler-tubes are supplied perfectly plain, without any screwing or other work upon them, and are held in place by passing them through a plate and expanding them in the hole, a taper ferrule being afterwards driven into the tube. To allow of this being done without damaging the iron, the end of the tube is generally softened by annealing. Iron tubes with brass or copper ends are often used in locomotives, as the iron, if attached directly to a copper fire-box, does not form a permanently good joint. Copper and brass tubes (also without screw-thread) are sold by weight, the price varying with the current prices of these metals from *9d.* to *12d.* per lb.

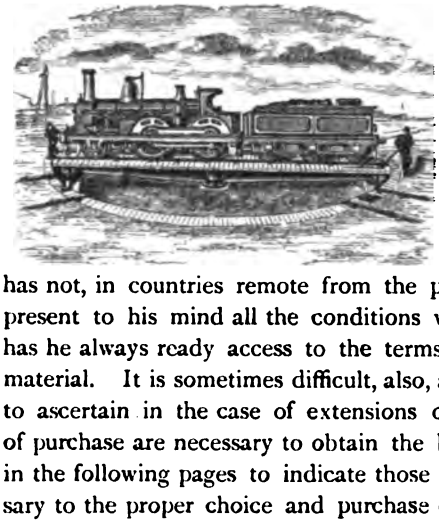
Choice of tubes, how determined.

In purchasing tubes, the purpose for which they are to be used should be stated; if of iron, whether lap or butt welded, and if of brass or copper, whether brazed or seamless. The exact length or the limits of length should also be stated. Bends, tees, and other connections, of which there is very great variety, are sold at prices per piece. It is also necessary to state whether the diameter given is external or internal and (except for gas tubes) the thickness, as there is no established rule as to what is meant when merely the diameter is stated.

[*See also* STEAM ENGINES: TRANSMISSION OF POWER: WATER-WORKS.]

CHAPTER XXIII.

RAILWAY EQUIPMENT.



See Chapters I. to IV.

Purchase of material.

See also pages 411–458.

In previous chapters, reference has been made to the inception of Railway schemes, and to the preliminary steps necessary to carrying them out. Even in the first equipment of a railway with material and rolling-stock, the engineer has not, in countries remote from the place of manufacture, always present to his mind all the conditions which determine choice, nor has he always ready access to the terms current for the purchase of material. It is sometimes difficult, also, after a railway is in operation to ascertain in the case of extensions or renewals what conditions of purchase are necessary to obtain the best result. It is attempted in the following pages to indicate those particulars which are necessary to the proper choice and purchase of the various kinds of Railway Equipment.

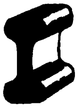
Permanent-way maintenance.

Design, how determined.

The "Permanent-Way" is in Great Britain the general name given to the track or road on which the trains run, and its maintenance, with that of the bridges and other structures on the railway, forms the chief duty of the Engineer as distinct from those of the Locomotive Superintendent, who maintains and controls the Motive Power and rolling-stock. There are various kinds of permanent-way, differing not only according to the system of construction, but also in regard to the strength and durability of the various parts, as determined by the nature of the traffic, the exigencies of climate, and by the money available. Whatever be the kind of track, it is made up of numerous parts, and, although some of these may appear unimportant, every one has to be repeated so many times that a right selection of even the smallest detail acquires an extreme importance, and, once established, is changed only with reluctance.

Rails.

Rails of various shapes and sizes have been tried, but three principal kinds were established in the early days of Railways, and have formed the rudimentary types from which most of the patterns since adopted have been developed. These are the *Double-headed* rail, the *Vignoles* or *Flange* rail, and the *Bridge* rail. The double-headed rail, so extensively used in Great Britain and sometimes in France, and other continental countries where railways were first constructed by English engineers, was adopted not only because of the strength it afforded, but also for the supposed advantage of allowing both faces to be used. This pattern of rail would not, however, have been retained as a leading type if there had been no other reason; for it was found that the lower face became so indented by the chairs on which the rail rested, as to be unfit for an upper surface, unless the rail were turned over so frequently as to prevent such indentations. The inconvenience and expense of this turning proved so great that the custom was soon abandoned. For roads laid on cross sleepers, the double-headed rail affords the great strength as a girder which is required between the sleepers, but as there is no longer the same necessity for having the top and bottom of the rail precisely alike, the upper bulb which is abraded by the wheels is now made larger than the lower bulb, and these "bull-head" rails, as they are termed, have become almost universal in Great Britain. One important point of difference between the double-headed rail and almost all other kinds is that the former requires iron chairs; and the trade in railway chairs would be at an end if this form of rail were discarded. Broadly it may be said that the double-head rail is used exclusively in Great Britain, and the flange rail almost everywhere else.



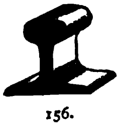
155.
Double-head rail.

Turned rails no longer used.

Bull-head rails.

Chairs required.

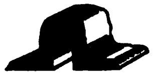
The *Vignoles* or *flange* rail is suited either for longitudinal or cross sleepers, and is deemed to have a sufficiently stable base without chairs. Under heavy traffic, however, the flange of the rail presses into the wood, and it is becoming usual in the United States to interpose a steel plate, although the case is partly met by laying the ties or sleepers, which are cheap in America, closer than is usual in England. Flange rails are generally fastened to the sleeper by spikes driven into the sleeper and gripping the edge of the flange.



156.
Vignoles or flange rail.

How laid.

The *Bridge* rail has been preferred by some engineers as being



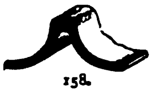
157.

Bridge rail as on G.W. Railway.

more symmetrical, and as having its wearing parts better supported than, as in a flange rail, by a single web. Bridge rails need longitudinal sleepers, this being the plan which was adopted on the Great Western Railway in England, where this form of rail was first introduced by Brunel for the 7-ft. gauge. Having thus a continuous support, much less strength was needed in the rail than where it had to span, as a girder, between cross-sleepers; consequently, bridge rails, even for heavy traffic, were usually only about two-thirds the depth and weight of double-head or flange rails. Bridge rails are spiked down to the sleepers, and at the junction of two rails they rest upon a base plate, which covers the joint. Such a connection is, however, inferior to the fishing-joint of flange or double-head rails, and longitudinal sleepers and rails so arranged, though allowing smooth running, were costly to maintain, for they needed constant attention, not only, as on all kinds of permanent-way, by adjusting the ballast, but by wedging and packing between the rail and the sleeper. Since the narrowing of the G.W. broad gauge took place, bridge rails are used on very few railways. Bridge rails of small light section were formerly much used for tramways in and about mines, and are still so used, but they have been largely superseded by flange rails. There is rather more labour in the production of bridge rails than of other kinds, and they are generally a few shillings per ton dearer. Old iron rails of bridge form are considered more valuable as material for reworking than other kinds.

Jointing.
See SLEEPERS. *page* 669.

Bridge rails now almost obsolete.

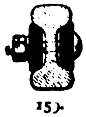


158.

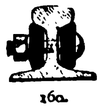
Barlow rail.

The *Barlow* rail, which may be considered as a development of the bridge rail, was at one time extensively used. Its wide base gives stability not only to the rail itself but to the whole permanent-way, and it is more independent of sleeper supports than any other kind. Indeed, it has in some instances been laid directly on the ballast to form rail and sleeper in one, although generally it is laid on longitudinal timbers. But when laid directly on the ballast it needs constant adjustment, and this circumstance, as well as certain inconveniences in regard to points and crossings, and also in the manufacture of the rail, led to its abandonment, and although still made in small quantities for special purposes, it is seldom employed on railways. It has been used on some railways as a cross-sleeper; in some cases also on locomotive turn-tables; piles have been made by riveting two rails together, flange to flange; and as the upper flange plate of a box-girder, it forms an effective beam for a travelling crane.

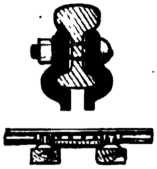
Disadvantages.



159.



160.



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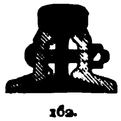
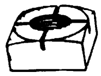


162.

Fishing-bolts.

Nuts and washers.



163.
Grip nut.

The two greatest improvements which have been introduced in connection with rails since railways were established are the Fishing-joint, and the use of Steel instead of Iron. In the early days of railways the joint was made by merely bringing the ends of two rails into one wide chair, but the connection was too weak, and was a source of danger when the rails were subjected to severe shocks. It is hardly necessary to state how immensely the fishing-plates add to the strength of a rail-joint, but they have the defect that there is in rails resting on chairs, no room for the fishing-plates at the places of support, and the rail, not being so strong at the suspended joint, yields slightly under the passage of heavy locomotives. Fishing-plates, both for double-head and flange rails, have been strengthened by making them deeper, the increased strength being obtained not by an actual grip at the under part of the rail, but by the greater depth given to the fishing-plate. The "bull-head" rails are convenient for this method of jointing; but the flange rail is also so jointed, the fishing-plate coming down to the edges of the flange and even below it. Even with these deeper plates, however, the rail is still weaker at the joints than elsewhere. It has been sought on some railways to overcome this difficulty by a special combination of cast-iron chair with the steel fishing-plates, the whole resting on the sleeper, but the details of this method have not proved entirely satisfactory. The deep fishing-plate is obtrusive and inconvenient, and, finding that it does not give all the strength expected, there has been a return on some railways to the original narrow form, the plates being made rather thicker than before. The need for constant tightening up of the fishing-bolts has led to the use on some railways of serrated washers and other devices for preventing the loosening of the nuts under the stress of traffic. No kind of washer has, however, proved effective for this purpose, and as it is found that the screwing up of the nuts is in any case necessary to compensate for the gradual stretching of the bolts, washers have, on some railways, been discarded altogether, and nuts used which have an initial grip preventing them from slipping back. These nuts, after the screw-thread has been formed in them, are sawn at four points for a portion of their depth and then squeezed in a press so as to constrict the diameter of the hole. When by extra force in screwing-up this constriction is overcome the nut holds tightly enough and will not slack back.

Bessemer steel rails.
See also pages 556–559.

The Bessemer inventions by which iron is converted into *Steel* rapidly, cheaply, and in large quantities, without the elaborate processes necessary in making wrought iron, have had their principal application and success in rails. Indeed, the introduction of steel rails has subjected the whole trade to a change unparalleled probably in any other branch of industry; new standards of excellence have been inaugurated, and, with them, new conditions of purchase. The methods of manufacture are really simpler and cheaper for steel than for iron; and iron rails may be considered as superseded. The steel rail has greater strength as a girder; it offers greater resistance to crushing; and its surface will endure abrasion longer. Steel rails not only wear out more slowly but more evenly than those of wrought iron; the latter, being composed of numerous pieces of iron "piled" together, laminate under the action of the trains, and the lurching of heavy engines shears long flakes off the heads; while steel, being homogeneous, only yields to traffic by the uniform abrasion of each particle. Those steel rails wear out quickest which are most subject to the influence of sand and skidded wheels. The less frequent expenditure in relaying the more durable steel rails, and the fewer interruptions by platelayers to passing trains, especially at station sidings and junctions where the traffic is great, are advantages which are now universally acknowledged. Steel rails will not bear the operation of hole-punching without injury; and even drilled holes weaken steel more than iron. It has been usual to notch the edges of flange rails for some of the spikes, so that the latter may prevent any longitudinal "travel" of the rail in the direction of the traffic; but even this notching of the flange weakens the rail, and such notches should be only at the ends, or avoided altogether in the rail, and made in the fishing-plate when it projects enough to allow it. It is generally expedient to adopt some existing pattern of rail, if the quantity required be too small to justify the cost of new rolls, and the pattern-books of manufacturers allow of ample choice. Every railway company has its own pattern of rail, but it would be a further advantage if standard patterns could be agreed upon by railway engineers generally, as makers could then roll rails and store them for sale afterwards, which, without established standards, they cannot venture to do.

Advantages of steel.

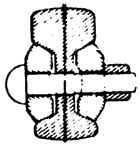
Homogeneous.

Durability.

Punching of steel rails.
See also page 560.

Steel weakened by notching.

Standard patterns.
See page 548.



164.

Fig. 164 shows the standard rail of the Midland Railway (England) in 1898. These rails weigh 103 lbs. per yard, and are laid in lengths of 36 ft., upon cast-iron chairs weighing 54 lbs., which have a bearing area on the sleepers of 110 square inches. The fishing-plates are 20 inches long and weigh 36 lbs. per pair. The bolts have grip-nuts (Fig. 169) without washers. Each chair is fixed to the sleeper by two trenails and two spikes.

Heavy engines need heavy rails.

On important lines the use of heavy engines and higher speeds have rendered necessary stronger and heavier rails than formerly; for while iron rails of only 60 lbs. to the yard were common in England in 1860, and in America till 1880, heavy steel rails of 90 and even 105 lbs. had in 1897 been adopted on the principal railways of England and the United States.

Rails sold by weight.

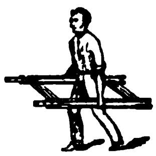
Steel cheaper than iron.

Light rails for little railways.
See pages 68–77.

Rails are always sold by weight, and in Great Britain by the ton of 20 cwt. Steel rails, which a few years after their introduction became cheaper than iron rails, have, since 1885, ranged in price from £4 to £6 per ton for heavy sections. Fishing-plates cost from £1 to £2 per ton more than the rails; fishing-bolts £10 more; and spikes from £6 to £8 more: but sometimes both rails and accessories are included in one average price. The average is generally from 5*s.* to 15*s.* per ton above that of the price for rails alone. Light rails are generally made in shorter pieces than heavy rails; more fishing-plates are consequently required, and the proportionate weight of plates and fastenings to that of the rails is greater.

Used by contractors.

For little railways of 2 ft to 3 ft. gauge, rails of from 15 to 30 lbs. are used; and for narrow-gauge railways of from 3 ft. to 3 ft. 6 in. gauge, with rolling stock of moderate weight, rails weighing from 30 to 50 lbs. per yard are sufficient. Contractors' rails for temporary use are made of all weights, from 10 to 40 lbs. per yard. The price of light rails under 50 lbs. per yard is from 5*s.* to 20*s.* per ton more than the price of the heavier sections.



165.

Portable railways.

Cost per mile.

Light steel rails may be so framed together with sleepers and ties in lengths of from 12 to 15 ft., as to form a portable railway, which may be readily laid down or removed by unskilled workmen. These railways are very useful for manufactories, brick-fields, farms, plantations, and mines. By the use of small wagons, weighing, when loaded, not more than two tons, rails of 10 lbs. per yard are sufficient for railways of 18-in. gauge; and for 2-ft. gauge, rails of 15 lbs. per yard are sufficient for the safe passage of locomotives weighing four tons, and capable of hauling 50 tons on a level. Railways, as above described, cost from £300 to £600 per mile, inclusive of switches, crossings, turn-tables, and wagons, according to the exact weight of the rails and current pieces of materials. If the capital outlay can be afforded, the higher price is the cheapest in the permanent advantages it affords.

Purchase of rails.

Simple as the definition of a rail would appear to be, a bargain for rails is an example of the importance of purchasers affording full information of their wants. If a manufacturer be merely asked the price of a certain quantity of rails of a certain section, and especially when, as is often the case, such an inquiry comes from abroad, no satisfactory answer can be given without a full specification of the conditions. The absence of such a specification disinclines manufacturers from paying serious attention to the inquiry, and vague statements are alone obtained, unless, with full particulars of the service required, the decision as to the form of rail be left to an engineer, or to the manufacturer, who should then be asked, on his part, to furnish a specification. The points which determine the price, and on which information should be furnished, are as follows:—

Specification. *See pages* 413 *&* 421.

Price, how determined.

1. The *Section* of rail required and the *Weight* per yard.

Section and weight.

2. *The Limits of Difference* in weight above and below that specified within which the rails will be received. A margin of 2 per cent. on single rails and 1 per cent. on the total quantity are usual limits.

Tolerance.

3. *The Length of the rails* and the degree of accuracy in this respect which is demanded. Rails weighing not less than 50 lbs. per yard are generally rolled 100 ft. or more in length and sawn into lengths of 24 ft. or 30 ft., while lighter rails are more usually sawn to lengths of 18 ft. or 20 ft. It is becoming usual on some of the principal railways in Great Britain and the United States to use longer rails, those weighing more than 90 lbs. per yard being in such cases laid down in lengths of 60 ft. As these long rails weigh from 1800 to 2000 lbs. each, they require numerous men to handle them, but they afford the great advantage of reducing the number of joints. A tolerance of about $\frac{1}{4}$ in., over or under the specified dimension, is usually allowed. Rails 100 ft. long are sometimes used on bridges. Rails of from 10 lbs. to 40 lbs. per yard are usually made in lengths of 18 ft. to 20 ft. In rolling rails, a certain number are found to be short or defective at the ends; and in such a case it is economical to cut them to shorter lengths rather than to waste the labour already bestowed on them. It is usual for the purchaser to accept these shorter lengths, if of certain specified dimensions, and if they do not in the aggregate exceed 10 per cent. of the whole quantity. Where such a concession is not made to the exigencies of manufacture, an extra price of from 5*s.* to 10*s.* per ton would have to be paid for the rails of standard length, to recoup the maker for the short rails which are wasted.

Usual lengths.

30 ft. usual.

60 ft. rails.

100-ft. rails on bridges.

Short rails, where and why allowed.

Testing of rails.
By falling weight.
Percentage of carbon.
See page 559.
Basic steel.
See pages 384 *&* 357.
Durability guaranteed.
Depends on traffic.

4. *The Tests* which the rails must satisfy. Strength and hardness against abrasion without brittleness are the qualities desired in steel rails, and these are ascertained by testing a certain number of rails with blows from a steam-hammer, and bending and breaking others by a falling weight. The proportion of carbon in the steel mainly determines the degree of hardness, and some percentage between 0·35 and 0·5 is generally adopted. It is seldom deemed prudent to exceed this maximum, especially for rails which will be exposed to intense cold. A harder steel would involve risk of brittleness, would also be slightly dearer in price, and add to the cost of drilling the rails. Sometimes the other chemical constituents of the steel and the process of manufacture are also specified, but it is a questionable policy to bind the manufacturer too strictly in these respects if he is made responsible for the results also. Basic steel is, however, often prohibited. Sometimes a guarantee of durability for a term of years is demanded; but manufacturers before agreeing to such a condition require full and trustworthy information as to the kind and amount of traffic.

Accessories.
Surplus fastenings.

5. The kinds and quantities of fishing-plates, bolts, spikes, or other *Accessories* which are required. Great care is necessary in arranging the holes in the rail to suit the fishing-plates and to ensure the proper position and jointing of the rails when laid in place, and these points should be exactly specified. Due accordance of the holes, plates, and bolts having been arrived at, uniformity is maintained by working to templates and applying gauges to every rail. Surplus fastenings are generally provided; 5 per cent. extra fishing-plates and 10 per cent. extra bolts and spikes being usual quantities.

Delivery.

6. *The place and periods of Delivery*. The expenses of transport bear a considerable proportion to the total cost of rails exported, and it is to the purchaser's advantage in inviting tenders to give the option of several shipping ports, so as to suit the localities of the different manufacturers.

Designing of rails, how determined.

Some of the foregoing conditions may be left to the discretion of the engineer or agent who purchases the rails, or even to that of the manufacturer; but it is then necessary that those who have to select or design the rails should be acquainted with the circumstances on which the choice must depend, viz.—

Arrangement of permanent-way.

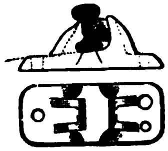
The gauge of the railway; the kind and quality of the permanent-way and ballast; the kind and arrangement of the sleepers (or free scope to design these also); the radius and frequency of the sharpest curves; the kind of locomotives in use, their weight when loaded, the length of rigid wheel-base on which the load is distributed and the maximum weight imposed by any one pair of wheels; the section of the wheel tires to which the head of the rail must conform; the probability of sand being frequently used (for the use of sand on slippery rails on steep inclines, and the skidding of the wheels, rapidly wear out the rails); the nature and probable amount of traffic per day which is expected to pass over the rails, and at what speed. Of course, where the rails are for a railway where patterns, rules, and conditions have been established and are well known, it may be sufficient, when making a bargain, to stipulate for the usual pattern and the usual conditions; but these conditions, even if well known, should be recited in each case before an absolute contract is made.

Curves.

Weight of engines.

Amount of traffic.

See page 413.



166.

Chairs are required principally for double-headed rails which lie on cross-sleepers, but as this form of rail is not largely used except in Great Britain, the quantity of chairs exported is small in proportion to that of rails. Chairs are made of cast iron, special machinery is used in the foundry for moulding them, and a much larger tonnage can be produced in a given time by a certain number of men than is possible with other castings, even of a simpler form, made by hand. The cost of production is proportionately low, and there are several foundries in England producing more than 1000 tons of chairs weekly.

Iron chairs.

Moulded by machinery.

The selling price of chairs ranges from £1 to £2 above that current for pig-iron, so that when pig-iron is at £2, ordinary chairs can be purchased for from £3 to £4. Chairs are made of size and weight according to the size of the rails, the distance apart of the sleepers, and the weight and speed of the engines. On British railways of the standard gauge, sleepers are generally placed from 28 in. to 39 in. apart, and the chairs weigh from 30 to 55 lbs. each. Locomotives are heavier than in the earlier days of railways; a larger bearing surface than formerly is needed for the rail; and the area of the base of the chair is therefore larger than formerly. It is on the main lines of railway, exposed to constant and heavy traffic, that chairs weighing more than 35 lbs. are used. Chairs are seldom used for flange rails, as these are held down to the sleepers by spikes, fang-bolts or clips; and chairs are still less necessary for bridge-rails laid on longitudinal sleepers. The special chairs used in

Price of chairs.

Weight.
See also page 663.

Chairs not needed for flange rails.

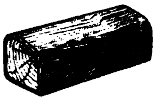
Tests. *See page* 541.

connection with points and crossings are supplied by the makers of these articles. In buying railway chairs it is usual to specify certain tests by which the quality of the iron may be ascertained.

Fixing of chairs.

167.
Trenails.

Iron spikes.



168.
Wooden keys.

Metallic wedges.

Chairs are fixed to wooden sleepers by iron spikes, wooden trenails, or by screws. Iron spikes by themselves are not effective, as the tremor caused by the passing of trains loosens the spike and causes it to rise above the chair. Hair-felt about $\frac{1}{4}$ in. thick is on some railways placed between the iron chair and the sleeper, in order to reduce the concussion under heavy traffic. Trenails are about 6 in. long, made of heart-of-oak, and are turned in the lathe to a diameter of about 1$\frac{5}{16}$ in., and then squeezed by hydraulic pressure to a diameter of 1$\frac{1}{8}$ in. The trenails fit tightly into holes in the chairs, through which they are driven into the sleeper, and the lower part in the sleeper swells, when exposed to wet, into its original diameter, so that it cannot come out; but in the course of time it is liable to rot and break off at the neck or shoulder below the chair. On the principal British railways where this system of fastening is adopted, two trenails and one or more iron spikes are used for each chair. Iron spikes cost from £2 to £3 per thousand, or from £4 to £6 per ton above the current price for ordinary bar-iron. Trenails cost about £4 per thousand. On some lines iron or steel screws are used instead of trenails. The rail is held in the chair by a wooden key or wedge, which acts as a cushion to deaden the percussion of the passing trains, and which can be driven in and tightened from time to time as it shakes loose. The keys are generally made of fir wood compressed, and those of a size suitable for a standard-gauge railway cost about £5 per thousand (fir), £7 (elm), and £8 (oak). Various kinds of metallic wedges have been tried, but except in hot countries (where spiral wrought-iron keys have been found suitable) nothing has proved so effectual as wood for double-headed rails held in cast-iron chairs.

Design of chairs.
How determined.

It is usual to furnish manufacturers with exact full-sized drawings of the chair required; and if a new pattern has to be designed, it must be based on the following data:—The *Section of the rail;* the method of *Jointing* the rail and the keying of the rail to the chair; the size of *Sleeper* and the kind of wood; the *Distance* of the sleepers apart; the maximum *Weight* imposed on the rails by any pair of engine-wheels, and the *Speed* of the trains.

Sleepers.

The *Sleepers* used on British railways are almost invariably made of wood, of a rectangular section; the timber being creosoted or

Kind of timber.

Cost.

Creosoting.

Distance apart of sleepers.

otherwise saturated with a preservative material, to prevent decay. Sleepers of half-round section are used on light railways or for temporary lines. The price depends mainly on the proximity of suitable growing timber, or the price at the nearest port where timber ships arrive, Baltic red wood (fir or pine) being the kind generally imported. In England from 5*d.* to 8*d.* per cubic foot is the range of price for half-round cross sleepers, and from 8*d.* to 12*d.* for rectangular sleepers. Half-round sleepers are generally 10 in. wide, 5 in. deep, and cost therefore from 15*d.* to 24*d.* each. Rectangular sleepers for standard-gauge railways are generally 9 ft. long, 10 in. wide, and 5 in. deep, and cost therefore from 2*s.* to 4*s.* each, to which must be added from 8*d.* to 1*s.* for creosoting. For lines of metre gauge or those of 3 ft. 6 in., rectangular sleepers, 9 in by 4½ in., will suffice; and for little railways of 2 ft. and 2 ft. 6 in. gauge, rectangular sleepers 7 in. by 2½ in.; the prices for these smaller sizes being not only less, but less per cubic foot, because they can be sawn from smaller and less valuable timber. On standard-gauge railways the sleepers are generally laid about 3 ft. apart; from 1800 to 2000 sleepers being required for each mile of single line. In the United States sleepers ("ties"), which cost only half the English price, are laid so closely—only 18 inches apart—as to form in effect almost a continuous wooden deck on the ballast. This closeness leaves scant room for packing the ballast, but allows for numerous spikes. The derailments under this system are more numerous than with the English permanent way.

Local supply of timber.

Shipment.
See page 445.

In constructing railways in any country the presence or absence of timber suitable for sleepers is one of the many local circumstances which determine the cost of the line. Large quantities of sleepers are imported into England from the Baltic timber districts, and, after having been creosoted or otherwise treated, are re-exported to colonial or foreign railways; and only rarely are such sleepers sent direct from the timber countries to their final destination. Difficulty arises sometimes in the shipment of sleepers, because of the deleterious effect which creosote has on other cargo; and it may become necessary or expedient to charter vessels expressly, or to take advantage of vessels carrying coal, iron, or other rough cargo.

Iron or steel sleepers.

In parts of India and other tropical countries, the ravages of ants are so destructive of timber that metallic sleepers have often to be substituted. Yet the prediction confidently made by engineers when railways were first introduced into India, as to the impossibility of

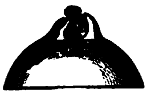
In tropical countries.

Seldom used in England.

using timber sleepers in any of the railways there, has not been wholly justified by later experience. Creosoted wooden sleepers continue to be imported into tropical countries, and in some cases indigenous timber is used; but the latter is generally harder than fir and more difficult to work, and it is necessary to bore the holes for the spikes. On railways under British control in non-tropical countries, timber is still generally preferred, but iron and steel are largely used in foreign countries. They have been used to a small extent in England also, but they are not likely to be widely adopted till the lessening supply of timber tends to raise the cost of wooden sleepers.

Substitutes for timber sought.

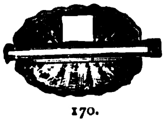
New inventions.



169.
Pot sleepers.

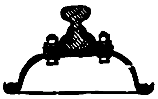
Weight and cost.

How laid.



170.
Oval pot-sleepers.

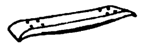
Much ingenuity has been directed towards the contrivance of substitutes for wooden sleepers; and the interests at stake are so large, and improvements, if effected, would be adopted on so wide a scale that invention has been stimulated to a more than usual degree. Not only have various systems of permanent-way been contrived, but each one that has found favour, or has appeared likely to succeed, has been seized upon by other inventors, who have altered, modified, or improved the invention sufficiently to justify a claim for a new patent. Since 1850 very large sums of money have been expended, and, to a great extent, wasted by inventors, manufacturers, and others in experiments connected with iron sleepers. A leading type amongst the earlier of such inventions is Greaves' "pot" sleeper, which not only has proved useful and successful, but has served as a starting-point for a variety of similar contrivances. This pot sleeper is of cast-iron, is circular, and in form is like an inverted bowl or saucer, the rail resting on the convex side against a chair or bracket cast upon it, the sleeper and chair being thus combined in one piece. These sleepers weigh about 80 lbs. each for standard-gauge or 5-ft. gauge railways, and cost from 10*s.* to 15*s.* per ton more than the current price of ordinary chairs. On standard-gauge lines these sleepers are placed about 3 ft. 6 in. apart under the centre of each line of rail, and are tied across the track by wrought-iron bars. A hole in the casting allows the platelayers to ram up or adjust the ballast below the sleeper. Several modifications of this sleeper have been made; an oval shape with two or three attachments instead of the one on the circular casting, being their chief characteristic; while in some the convex bowl is made of a corrugated or undulating shape. The oval or elongated castings weigh about 100 lbs. each, and, when worn out or broken, have a value as old iron for re-melting. In



171.
Steel sleepers.

How made

172.
Rolled steel sleepers.



173.

Pressed in dies.

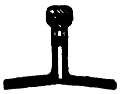
Clips and fastenings.

Thickness, weight and cost.

devising substitutes for wooden sleepers, rolled iron or steel has been generally preferred to cast iron. The greater weight of cast iron is an advantage after the track is laid, but the weight and liability to fracture are disadvantages for transport. Cast iron is more durable against rust than wrought iron or steel, and its greater thickness can better afford wasting by rust. On the other hand, cast iron is the less elastic material, and is unsuitable for laying on a hard road-bed. Some wrought-iron or steel sleepers are of the bowl type, round or oval, smooth or corrugated, and are made by being pressed in dies while hot. Some are rectangular, and are of the self-contained buckled plate arch form. There is a much greater variety than in cast iron, although the scope of the designer is more limited by the exigencies of manufacture. None of these shapes, however, are so well adapted for double-head rails as for flange rails, and consequently, engineers on the Continent, where the flanged rail is almost universally used, have given most attention to the subject. Everything connected with the permanent-way of a railway is wanted in such considerable quantities that the relative cost of different systems goes far to determine choice. To this end, a shape which can be made in a rolling mill has been the aim of some designers, and a trough form, which can be rolled like a channel bar, has been adopted on some railways. But such sleepers do not sufficiently grasp the ballast, and a great improvement in the parallel trough is that in which the sleeper is widened out where the rail rests and is closed at the ends. These sleepers having first been rolled from a flat plate, are at the same heat pressed between dies into the desired shape, and immediately dipped, while hot, into a bituminous compound which prolongs the durability of the steel against rust. The need for loose clips and fastenings is avoided by punching up a portion of the steel itself, and these raised portions when doubled back serve as jaws or cleats for the rail to rest against. Sleepers of this kind range in weight from 40 lbs. for little narrow-gauge railways to 140 lbs. for standard-gauge lines subjected to heavy traffic. Wrought-iron and steel sleepers have been generally made about ½ in. thick, and being about one-third the weight of cast-iron sleepers, and costing less than three times as much per ton, the expense is rather less, and much less in regard to carriage.

Attachment of rail to sleeper.

There is also much variety in the mode of attaching the rail to the sleeper. Bolts, cotters, and clips of different kinds have been designed, but the simplest are generally found to be the best as well as cheapest. Most metallic sleepers are, as above described, adapted to rails of ordinary kind, but in some cases, instead merely of a modification of the sleeper, the whole permanent-way is modified, and rails have been specially contrived like a single bulb-iron, without a flange or other protuberance at the bottom, so that they can lie between two iron supports, which together form a longitudinal sleeper.



174.

Timber and steel compared.

In tropical countries the economical advantages of native or imported timber on the one hand, and of steel sleepers on the other, often meet, and a choice depends on a variety of considerations, of which, the first cost and the durability are not alone conclusive. The annual interest on the capital outlay, the annual provision necessary for depreciation and renewals, the cost of labour in relaying, as well as the value of the old material, are incidents of great importance.

Choice, how determined.

To allow a proper choice of sleepers, the following information is necessary :—

Rails.

1. The *Section of the rail*, the gauge of the railway, and the gauge of the "six-foot" (*entre-voie*).

Road-bed.

2. The material of the road-bed or kind of *Ballast*, and thickness of ballast available or proposed.

Locomotives.

3. The kind and weight of the *Locomotives* and rolling-stock, with the maximum weight on one pair of wheels, and the speed of the trains.

Climate.

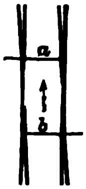
4. The *Climate*, not only in regard to extremes of temperature, but also as to the rainfall, and its effect on the permanent-way.

Timber.

5. Information concerning the kind and cost of indigenous or imported *Timber*, and its liability to damage by ants or vermin.

Switches and points.

Switches, or points (*rails mobiles*), are made of the same material—iron or steel—as the rails. Great ingenuity has been exercised in connection with switches, and modern invention has reduced to a minimum the risks that must always attend the passage of trains through the points, especially facing-points. The risk is obviously much greater at facing points *a* than at trailing points *b*, and therefore the former are avoided as much as possible on main roads, it being preferred that the trains should back when passing on to a siding. Facing points are, however, unavoidable at junctions, but on modern railways the points and switches are so accurately made and fitted, that fast trains can pass over them safely. Even a slight obstruction or derangement of the points will affect the locking gear of the levers and signals, and automatically prevent accident. Owing



175.
Facing and trailing points.

Cost.

to the great variety of rails used on different railways, the switches also necessarily vary in their details. From £16 to £25 is the range of prices which covers most of the different kinds of switches made of steel (including rods, levers, and boxes). Generally, rails of the kind and pattern used on the railway are supplied to the manufacturer, who, having the cost of the material thus saved to him, makes the rails up into switches at about two-thirds of the above prices.

Switches for narrow gauge.

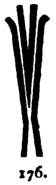
Choice, how determined.

These prices are for standard-gauge railways; for narrow-gauge lines, with rails not exceeding 40 lbs. per yard, the prices range from one-half to three-fourths of those stated above. To enable a manufacturer to supply suitable switches, he should be informed of the section of the rail and the system of permanent-way; the gauge of the railway and that of the six-foot; the radius of the turn-out; and whether the railway is to be a durable one for busy traffic or merely for temporary or infrequent use.

Crossings.

Chilled iron or steel.

Crossings are made either of steel rails or of solid cast steel, or of cast iron "chilled" by being cast in iron moulds, which process, by cooling the metal quickly, gives an intensely hard face. Chilled-iron crossings are more durable than any kind of steel, and for situations of minor importance or for slow-speed traffic are best as well as cheapest. For fast-running trains, however, where steel rails are used, crossings made of steel rails are preferable, as they have the important advantage of being similar in regard to strength and elasticity to the rest of the road. This circumstance outweighs the greater durability afforded by the more rigid chilled-iron crossing.



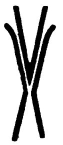
176.
Angle 1 in 5.

Variety of form.

Cost.

There are many varieties of crossings, the choice depending mainly, as is the case with switches, on the gauge, the weight, and section of the rails, the nature of the traffic, and the position of the crossing in relation to the main roads. On these circumstances, and on the accessories which are required, such as check-rails or special chairs, the price also depends; but a range of from £10 to £15 includes almost every kind. The angle should not be finer than 1 in 10, nor coarser than 1 in 5. For light rails, or for temporary or contractors' purposes, a set of points, including switch and crossing complete, costs about £16. Where a siding crosses a main road without connecting with it, what is known as a "diamond crossing" is used. If the lines cross at too sharp an angle there is a risk of the train wheels leaving the proper track, especially if the train has to be started when on the crossing. The angle should not be sharper

Diamond crossings.



177.
Angle 1 in 2½.

Cross-over roads.

than 1 in 6½ when there is full scope for choice; and the regulations of some railways forbid a sharper angle than 1 in 8, although an angle even of 1 in 12 is sometimes ventured on. Engineers and others should, in purchasing crossings, specify clearly what they wish to include, because the term has different significations. Thus, by a railway engineer or contractor, a crossing is often intended to mean the entire material for crossing from one line to another, and not only includes the switch and crossing pieces, but the rails that join one line of rails to the other. And even more than this is sometimes included where a "cross-over road" crosses several lines of railways. But by a maker of such things, a crossing means, if not otherwise specified, only the actual crossing-piece. In such cases, therefore, it is necessary not only to state the gauge of the railway, the gauge of the "six-foot," and the section of the rail, but to furnish a sketch showing the position of the lines of railway which are to be joined and the angle of the roads.

Turn-tables.

Less used than formerly.

Engine turn-tables.
See page 659.

How balanced.

Turn-tables have been in use from the earliest days of railways, both for engines and carriages, but for the latter purpose they are not used so freely as formerly, as they occupy much space, and are an obstruction on the permanent-way. They have been superseded in many situations by traversers. The earlier turn-tables for locomotives required elaborate racks, winches, or other gear for turning them, a process occupying five or more minutes. Now, by balancing the turn-table carefully, it can be easily pushed round by one or two men in half a minute. The diameter of a balanced turn-table of this sort must be from 3 to 6 ft. greater than the length of the wheel base of the engine and tender, because the centre of the wheel base seldom coincides with the centre of gravity of the engine; the latter varying also according to the quantity of water and fuel in the tender. In order that the turn-table may revolve freely, there should be no pressure on its outer wheels (which serve only to sustain such portion of the weight as may be unbalanced), but all the weight should be borne by the centre pivot. An experienced engine-driver will accomplish this by bringing his engine to a standstill at such a point that the centre of gravity shall be exactly over the centre pivot; and the turn-table, with the load thus adjusted, is easily pushed round.

Diameter.

The great length and weight of a modern locomotive with its tender have rendered necessary larger and stronger turn-tables than formerly, and instead of 40 ft. maximum diameter, 42 ft., 45 ft. and even 50 ft. are often required, and the effective diameter can be, by a simple arrangement, temporarily increased. In the United States, turn-tables from 50 to 60 ft. diameter are made to suit the long engines and tenders in use there. It is very important that a turn-table be of great strength, so that it may not deflect under the load; it must be well fitted so that it balances and moves easily; and the central pivot and its bearing must be effectually hardened.

See LOCOMOTIVES, *Chap. XXIV.*

Cost of Turn-tables.

A locomotive turn-table 40 ft. in diameter of the best modern construction, and inclusive of the ironwork beneath it, costs from £350 to £400, or if covered with a floor of iron plates, from £400 to £500. For turn-tables of greater or less diameter than 40 ft. an addition or deduction of about £10 per foot of diameter should be made. To the above prices must be added the cost of excavating and lining the circular pit in which the turn-table revolves, and of building the foundations of masonry or brickwork on which the iron pivot and rails will rest. If only one siding passes over the turn-table the circular wall need only be built where the sidings come. Sometimes for small turn-tables, the circular lining is iron instead of brickwork. Centre balance turn-tables should be fitted with relieving apparatus at the ends, so arranged as to wedge up the table to the outer bearings to give it stability and steadiness there while the engine is entering or leaving it.

Depends on size.

Foundations.

Carriage turn-tables.

Turn-tables for carriages and trucks are made from 12 to 20 ft. diameter, and for those made of iron the prices range from £7 to £11 per foot of diameter, the higher rate including the cost of iron plates on the top, instead of the wooden floor which is often used, but which is liable to ignition from the locomotive. Small turn-tables 6 ft. diameter, cost from £25 to £30 if wholly of iron, and such turn-tables are useful on wharfs and landing jetties. Small iron turn-tables for railways of from 1 ft. 6 in. to 2 ft. 6 in. gauge, such as are used at mines and quarries, cost £5 to £15.

Small turn-tables.

Carriages are seldom turned for the mere purpose of reversing their position in a train; but many station yards are so arranged that a partial turning of the carriage is necessary for the marshalling and arranging of trains. Turn-tables are generally placed on sidings, and they should not be placed on main lines, or where running trains may have to pass over them. The large carriages on 4 or 6-wheel bogies used as dining or corridor-cars have seldom to be turned, but when this operation is necessary, a locomotive turn-table must be used, or the cars reversed on a triangle track.

Triangle tracks.

Traversers. **When used.** **How propelled.** *See page 523.* **Cost.**

Traversers, by which engines or carriages can be transferred from one line of rails to another across the station or station yard, are made of a length to suit the rolling stock. Engine traversers are rarely used except in repairing-shops, where they sometimes afford a convenient means of bringing an engine into or out of the shop. In such cases they are propelled either by a small engine fixed on the traverser or by a quick-running cotton, hempen, or wire rope, worked by an adjacent fixed engine. Although carriages measure (including the buffers) from 22 to 34 ft., the traverser need be but little longer than the wheel base. Traversers are principally needed where space is limited for shunting, and they are seldom required where space is ample and the traffic is small. Engine traversers cost from £400 to £600, and about £200 more if a propelling engine is added. Carriage traversers cost about £100.

Design of traverser. **How determined.**

The choice or design of a turn-table or traverser depends on the following points, concerning which full information is necessary: The gauge of the railway and that of the six-foot; the section of the rails; the dimensions and weight of the engines or carriages, a diagram showing the position of the wheels and the weight on each pair of wheels. If for engines, a longitudinal and cross view should be furnished, showing the extreme projecting parts, such as the coupling-rods, cylinder-cocks, and cattle-guards. If for carriages, the shape and dimensions should be indicated by a profile showing such projections as foot-boards and steps. It is needful also to furnish a sketch of the site on which the turn-table or traverser is to be fixed, indicating adjoining lines of rails. The addition of a propelling engine is determined partly by the cost of manual labour.

Buffer stops. **Hydraulic stops.**

Buffer stops on sidings are generally constructed of timber and steel rails, but at important terminal stations more elaborate structures are often required. Hydraulic buffers have proved effective and convenient, as they allow a longer stroke or travel of the buffer and an easier arrest of the train than is afforded by the more usual arrangement of springs. The hydraulic buffer piston moves in a cylinder against water which, as it is propelled forward, is allowed to escape through orifices constricted as the piston advances, so giving the effect of a gradually compressed spring.

Signals.

Signals of a very simple kind were used in the earlier days of European railways, and the subject demanded and received but slight attention. This is still the case on many foreign railways where the traffic is small, and signals are altogether wanting on railways in new countries where there are few trains. On the principal European lines, especially those in England, the multiplication of junctions and crossings, the vast increase of traffic, and the running of quick passenger-trains and slow goods-trains on the same line, have rendered elaborate precautions necessary for safety. The most notable changes in signals in recent times have been connected with the "block system," which may be briefly described as the enforcement of an absolute distance, or space of rails, between trains following each other on the same line, instead of the mere interval of time which used to be relied upon, and which was the cause of many accidents. Signals being placed at intervals, generally ranging from a quarter of a mile in the vicinity of a station to two or three miles between stations, no train is allowed to pass one such signal till the preceding train is announced to have passed the next one in advance; the electric telegraph being, of course, essential to this system. The tendency of modern improvements has been towards automatic security, which may be defined as the prevention by mechanical means of the display of opposing signals which would involve or allow collision. By an ingenious system of "interlocking" the different levers, it is impossible to move any lever till all others—and with them the signals worked by them—are secured. This plan has been still further improved by bringing into the same interlocking system the levers working the points or switches, so that, except by a positive disregard of signals, no train can advance in a direction which will involve collision. The interlocking of levers and points and the electric block system have been also combined, attaining—though at considerable expense—a high degree of automatic perfection. Accidents having occurred through the imperfect closing of points for the passage of an approaching train, and through the altering of points before the whole of a train has passed, the points are now further protected by the addition to the apparatus of the "facing-point lock," which secures the proper closing of the points before a train can be signalled to approach, and prevents any moving of the points whilst a train is passing over them, no movement of the points being possible even by wilfulness or inadvertence on the part of the operator till the whole train has passed. The passage of trains through stations, or into sidings or on to junctions, is thus made safe; and a quick succession of trains rendered possible. At a few of the more important junctions and stations in England the number

Busy traffic needs special precautions.

Block system.

Automatic security.

Interlocking levers.

Signals and points connected.

Facing-point lock.

Passage of quick trains through stations.

Numerous levers in one house.

Cost.

Improvements in details.

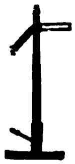
See TRANSMISSION, *page* 511.

of levers in one signal-house exceeds 250, while groups of from 20 to 100 are very common. Each point or switch, and each signal requires one lever (sometimes two points are connected with and worked by one lever), and the cost of the interlocking apparatus, exclusive of the cost of the signals themselves or the switches, may be stated approximately at about £7 per lever; and including the cost of signals, connecting wires or rods, house and telegraphic apparatus complete, £25 to £35 per lever. Concurrently with the elaboration of signalling, improvements have been made in the mode of constructing the signals. Malleable cast iron and steel have been substituted for certain parts formerly made of cast iron; and tubular rods or solid bars have been substituted for many of the moving parts formerly made of wire.

See page 4.

Various forms of signals.

These mechanisms are in Great Britain considered so essential to safe railway working as to be made compulsory by the Board of Trade authorities, whose sanction is necessary to the opening of new lines for passenger traffic. They are available for foreign countries when the traffic grows large enough to require it, but the simpler forms of single signals are still all that are required on railways where the traffic is small. The various discs, arms, semaphores, and other means of indicating *safety*, *caution*, and *danger* which were adopted independently on different railways, have entirely given way to the one simple kind of "semaphore," the universal adoption of one form of signal greatly adding to the simplicity of railway working. Only two signals are now indicated: at night by lamps, red for "stop," green for "full speed"; and in daylight by semaphore arms at 90° and 45°, the third or *nil* signal having been abolished, as it might be given by the action of the wind. In Great Britain the principal railways have agreed on a common code of regulations in these matters.



178.
Semaphore.

Height and cost of signal posts.

Steel posts.

A semaphore post of wood 20 ft. high, with arms, lamps, and all appurtenances, costs from £16 to £20, which is increased to about £30 if the wire and extra gear necessary for working it as a distant signal be included. When required of a greater height than 20 ft., the price of the post increases by about 10*s.* per foot up to 40 ft. In countries where suitable timber is procurable, expense may be saved by importing only the ironwork and fittings. Posts of light steel framework are also used, and are very suitable for countries where timber is expensive, or for climates destructive of wood; they cost in England from 15 to 25 per cent. more than wooden posts.

When it is desired, for a foreign railway, to obtain the advantage of the latest English inventions and experience in regard to the signal equipment of a junction or station, the following information should be furnished to the engineer or manufacturer to whom the choice, design, or purchase is entrusted.

Station signals, how designed.

1. A *Plan* of the station or junction showing the positions of the different lines and sidings, with a description of what each line is used for, the direction in which the traffic runs on each line being indicated by arrows; the curves on the approaches; and any objects which may interfere with the view of the signal by the driver of an advancing train, and which may render lofty signal posts, repeating-signals or special positions necessary.

Plan of railway and sidings.

2. An approximate description of the number and length of *Trains* and the intervals of time between them; distinguishing through trains from those which stop or shunt. The probabilities as to future increase in the traffie should be stated.

Number and length of trains.

3. The *Speeds* at which the various trains pass through the station.

Speeds.

4. The amount and nature of *Shunting* and marshalling; the relative amount of passengers, goods, and mineral traffic to be deal with being stated.

Shunting.

3. The *Gradients* for at least one mile on either side of the signals.

Gradients.

6. Whether the *Electric-telegraph* is in use, or is intended to be used, for signalling between stations, or is available for the purposes of the railway.

Telegraph.

7. The kind of *Signal already in use* on the railway or on the other lines with which it is likely to be connected.

8. Whether *Gas or oil* is available for the lamps, and if oil, its kind.

Gas or oil lamps.

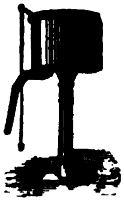
9. The nature of the *Climate* and the local circumstances affecting the transport of material, especially of long signal posts; and the facilities for repairs.

Climate.

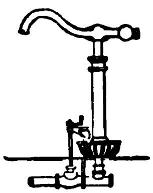
Water-cranes, and other apparatus for supplying the tank of a locomotive, depend for their arrangement mainly on the source from which the water is to be obtained and on the frequency and importance of the supply required. Thus, on a contractor's temporary railway, or where a minimum outlay is of importance, an ordinary hand-pump may be used to lift the water from a well or pond and deliver it into the engine-tank through a hose-pipe, the latter being

Water supply for locomotives.

for convenience attached to a post. Such an apparatus would cost from £12 to £25. Even in England hand-pumping is often employed at small stations, but an elevated tank is always employed, so that though the pumping be slow, the engine can be quickly supplied from the tank. The latter may, for temporary service, be cheaply made of wood. If the tank be placed near the railway, a projecting pipe or swinging-jib can deliver the water to the engine. A circular tank for holding 1000 gallons and complete with supporting column, valves, and hose, costs about £90. Even where water-mains for railway or general purposes are sufficiently near to be utilised, a tank is necessary to ensure an immediate and abundant supply for the locomotives. Sometimes the tank is at a considerable distance from the swinging-jib, and an iron column or stand-pipe is needed. If made with a swinging-jib, as a separate and self contained structure, it is known as a water-crane. One of these, as above described, with valves complete, costs, from £35 to £60, according to kind and quality; an additional cost of about £5 being incurred if a fire-grate or stove is attached for preventing the water from freezing in cold weather. Cast-iron tanks are generally preferred as being more durable and more easily put together than wrought-iron tanks, and except that the pieces are liable to damage in transit, are, in most respects, better than tanks of wrought iron. A capacity of from 4000 to 12,000 gallons is suitable for the purpose, but of course a larger tank is needed if the water-supply is intermittent and storage is necessary, or if the number of locomotives taking the water is great. At important stations, tanks holding 100,000 gallons are provided. The apparatus should be at least equal to filling the largest tender in five minutes. If the water be very hard or contain too much lime, it can be softened by an inexpensive process.



179.
Tank and water-jib.



180.
Water-crane.

Cast-iron tanks.
See page 639.

Large tanks.

Where there is no independent source of water from which the tank or water-crane can be supplied, and where hand-pumping is not convenient or sufficient, a pumping-engine becomes necessary, and its cost depends primarily on the depth from which the water has to be lifted. When a pumping-engine is employed for this purpose, it is usual to make the tank large enough for supplying the station buildings and for general purposes. A pumping-engine complete, with boiler of the kind usual for this purpose, will cost from £80 to £500, according to the exigencies of the case. But at small stations, or where water is only needed in small quantities, a steam-engine

Pumping-engines.
See page 614.

may be avoided by the use of a gas-engine, hot-air engine, petroleum-engine, or by an electric motor. The latter can be economically applied where there is already an electric-lighting installation, as the motive power can be utilised in the day time, and the current transmitted half a mile or more to pumps for filling the storage-tanks.

See page 508.

Water drawn up by elevator.

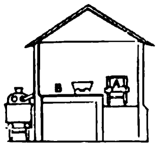
Risk of impure water.

Feed-troughs to supply trains while running.

Locomotives may be rendered partly independent of water-cranes and tanks by having permanently attached to them an "elevator," which, by means of steam from the boiler, will draw up through a hose-pipe water from any contiguous pond or stream. But the durability of the boiler depends greatly on the quality of the water, and there is a risk of impure water from a chance supply. The system has been adopted on some railways of a feed-trough laid between the rails and kept filled with water, which, as the engine advances, rushes up a shoot lowered from the tender. About half-a-mile of level track is essential to this method, which has been adopted both to obviate the necessity for stopping the trains and to procure a supply of better water than may be found at a stopping station.

Fuel and water-supply combined.

Elaborate arrangements are usual at large railway centres or important stations where the traffic is great. The supply of water is then arranged in conjunction with that of *Fuel*, and a covered platform, with coal-stores, cranes, and water-jib, is specially contrived. The wagons, A, conveying the coal are brought by an incline on to a raised stage, so that the coal can be easily filled into small carriages, holding about 5 cwt., and these in their turn are discharged, B, into the tender. By this means the cost of coaling has been reduced from about 6*d*. to less than 2*d*. per ton. At important stations the stage is a double one, the coal wagons being in the centre, the locomotives being supplied on either side. A proper design for such a stage or platform depends on the following information, which should be supplied to those concerned:—



181.
Coal stage.

Arrangements, how determined.

1. A *Plan* of the site available, showing the lines and sidings and the approaches from the main line and adjoining station, with their gradients.

2. The *Gauge* of the railway and the kind of permanent-way.

3. The sources of the *Water-supply*, with its pressure or levels in regard to the level of the rails.

4. The kind of *Fuel* used and the quantity usually stored.

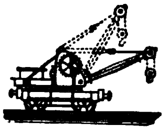
5. The *Number of engines* to be supplied daily; the shape and length of engine and tender.

6. The *Storage* capacity of engine or tender tanks and the maximum consumption of water per mile.

7. The extremes of *Temperature.*

8. Whether a *Water-softening* apparatus is required, and if so, a sample or analysis of the water should be furnished.

9. The kind of building *Materials* available.



182.

Break-down cranes.

See also page 793.

Useful also for loading goods.

See page 684.

Narrow-gauge cranes.

"*Break-down*" *cranes*, as used for clearing a railway after an accident, are jib-cranes mounted on railway trucks. They are generally provided with a loaded box for a balance-weight, and the jib will lower down to allow the crane to pass under bridges; the jib as it is raised, increasing in power as the radius it commands becomes less. These cranes are also useful for loading timber or other goods, and for this purpose can be sent to roadside stations which are not provided with cranes sufficiently powerful. Break-down cranes, completely equipped for lifting 5 tons, cost from £350 to £400 each; and for 10 tons, from £500 to £600 each. These prices are for cranes suited to the standard gauge, and include the expense of screw-jacks, crowbars, clamps and other usual accessories. For narrow-gauge railways a capacity of 4 tons and 8 tons respectively is more usual, at prices rather less than those just named, but such a narrow base does not of itself afford sufficient stability, and it is necessary to anchor the crane-carriage to the rails. As a considerable part of the cost is for the travelling wagon, which must have buffers, springs, and usual appurtenances, like other rolling stock, to render it safe when travelling as part of a train, cranes in other respects similar, but without springs and buffers, and furnished only with small wheels, can be purchased for about 20 per cent. less. Cranes so made are often used on landing-piers and in factories adjoining a railway. A break-down crane should be accompanied by a van or wagon carrying a vice-bench, chains, screw-jacks, tools, and lamps; and the tool-van and crane should always be kept in readiness, fully equipped, with lamps trimmed; and workmen appointed, who should be at call whenever the crane is required.

Railway bridges.

See page 133.

Bridges, either over or under railways, depend for their design and cost on the local circumstances of each case; and the points which determine the design have been already fully described. One main point of difference between a road bridge and a railway bridge is that while the former requires a strong floor to support a load over its entire surface, a railway bridge has its load confined to the rails, which can, if desired, be supported by a mere skeleton or framework bridge. If, for the sake of cheapness, railway bridges are made in this way, there is the obvious disadvantage that, in case of the derailment of a train, the carriages are liable to fall through the bridge. As a precaution, it is usual to lay the rails as in a trough, between balks of timber, so that the wheels cannot jump the track. Economy is sometimes also sought by the omission of parapets, a practice which is not favoured in Europe. It is difficult to keep the floor of a railway bridge water-tight, as the vibration of heavy trains tends to open caulked iron or timber seams; and in towns where bridges pass over streets, this circumstance is often a cause of great inconvenience. The difficulty is enhanced on "through" bridges, where it is attempted to make a water-tight joint between the floor and the main girders. It is generally better in such bridges to construct the floor as a water-tight tray (lining it with elastic asphalte) free of the main girders.

Frame bridges without floor.

Parapets omitted.

Water-tight floor.

Through bridges.

See page 137.

In allowing a certain margin of strength or "factor of safety" when a bridge is designed, wasting by rust and the possibility of heavier locomotives being used at a future time should be taken into account. It is not only the total weight of an engine but also its distribution on the wheels which determines the effect on the bridge. Tank and other engines, in which a great weight is concentrated on a short wheel-base, impose very severe strains on the bridges over which they pass, especially on the cross girders. The engineer of the line and the locomotive engineer should be in accord concerning these matters, for in designing new engines not only must the general strength of the bridge be considered, but the strength also of the cross girders and rail-bearers, to sustain the weight concentrated on the driving wheels. On some railways, since about the year 1896, the plan has been tried of stiffening the floor framework of bridges by laying the permanent-way with 100-ft. rails. The difficulty of carrying such rails to the site of the bridge is the principal impediment to this plan. There is no difficulty in making the rails.

Provision for wasting by rust.

See page 149.

Increasing weight of engines.

100-ft. rails.

The kind of *Station Buildings* for passenger accommodation or for goods traffic depends so entirely on the particular circumstance of each railway and station that few general rules can be given. Where railways have to be made cheaply in a new country, or amid a sparse population, very simple structures may suffice at the commencement. If the trains be few in number, waiting-sheds or huts, costing from

Station buildings.

Of simple kind for cheap railways.

£20 to £100 each, may suffice as roadside stations; the selling of tickets and transfer of luggage being entirely managed by the conductors who travel with the trains. And even where stations for goods as well as passengers have to be provided, buildings of a simple kind, quite unlike those usual on busy railways, may prove sufficient till the traffic has developed. Covered sheds for perishable goods, and facilities for loading and unloading vehicles conveying goods to or from the station, are among the first works which are necessary to the development of traffic. Where the need for cranes is likely to occur only rarely, a travelling jib-crane may be brought for the purpose, when occasion arises. But though the outlay for stations may often be wisely limited or postponed till increasing traffic indicates the nature and extent of the buildings required, it is always advisable to secure ample land space for stations hereafter, as the value of land, even if not needed for the purposes of the railway, almost always increases if near a station.

Traffic managed by train-conductor.
See page 61.
See page 682.
Ample land space should be secured.
See page 64.

The experience which has accumulated in regard to the most suitable forms of buildings in different climates is available to the engineer who designs the railway, and who will generally endeavour to utilise the materials of the locality—though very often the iron-work and sometimes the entire structures have to be imported. Much of the local information which should be supplied to the designer is described in other chapters. No rule can be given for the cost of station buildings, for not only the cost of the materials but the standards of excellence vary in different countries. In Great Britain, on the best railways, a certain comfort and completeness are required by law, and have to be given to all the rooms and offices connected with a station, so that even for village stations the cost will range from £400 to £800; and as traffic increases, the rules established by the government departments which regulate railways become more onerous. Such an outlay is seldom necessary on foreign railways.

Design depends on locality.
See Chaps. IV. and XXX.
High standard of excellence on British railways.
Official rules.
See pages 4 & 75.

In parts of South America and other countries, where building materials are scarce, stations almost entirely of iron are imported from Europe. Such structures are generally composed of cast-iron columns united at the top by cast-iron spandrils or girders, on which rest a cornice and rain-gutters, the girder and gutter being sometimes combined in one casting. Upon the girders are placed wrought-iron framed roof trusses or principals, which are generally made of some span between 15 and 40 ft. The sides of the buildings are composed

Iron buildings.
See page 860.
How constructed.

Corrugated iron. *See pages* 553 & 871.

Wood linings and partitions.

Resistance to wind.

of sheets of corrugated iron, and the roof is covered with zinc, corrugated iron or tiles, laid upon wood boarding or iron laths. Wooden doors, glazed windows, and the necessary internal fittings are also generally imported. Greater finish and completeness may be given to the buildings by lining the sides, partitions, and roof with boarding. Sometimes, even where the station buildings are made entirely of local material, verandahs or sheds for covering the platforms are imported. Structures of this kind may be made very light, but in this respect the climate and the liability to strong winds have to be considered. In the case of iron buildings there must of course be added the cost of transport, of levelling and draining the site, and the cost of erecting the structure.

Large terminal stations. *See also pages* 869 & 881.

Cost according to area.

For terminal or other important stations, where imposing buildings and large-span roofs are required, great expense may be incurred. Owing to the great area enclosed by such buildings, their high cost as compared with smaller stations is not immediately apparent, if the cost per cubic foot be alone compared. The roofs of large span erected in England for important terminal stations have cost from five to eight shillings per superficial foot.

Design, how determined.

To allow a proper design to be made for a railway station, information is required on the following points:—

Plan of site.

Length of train.

1. A *Plan and Section* of the railway at the place where the station is required, showing the lines of rails, the sidings, junctions, and signals, the land available for buildings, and indicating the position, nearest the town or otherwise, most suitable for the offices; the length of the trains which stop at the station, and a cross-section of the rolling stock, showing the height of the floor from the rails, and a profile of the steps, roof, and loading-gauge. The roads and approaches with their levels in relation to the railway must be included in the plan and section, so as to show how vehicles and goods will arrive at and leave the station.

Rank or importance of station.

2. The *Rank* which the station will occupy on the line, as first, second or third rate—a definition which may be made according to the following circumstances: the size and population of the towns or villages adjacent to and making use of the station; the number of trains through, and the number stopping at the station, as indicated by a copy of the time-table.

Number of passengers.

3. The approximate *Number of passengers* arriving at or departing from the station, and the anticipated proportions of first, second, and third class; the number of railway servants who will be employed,

and their grades, and whether living accommodation is required for the station-master or servants, and for how many; whether the passengers bring much luggage with them; whether parcel traffic is to be provided for; whether a mail room, or a postal or telegraph office, or a refreshment room is required; if so, on which side of the station these rooms should be provided.

Amount and nature of traffic.

Social rank of passengers.

4. The kind and social *Rank of people* who will use the station, so far as will help to determine the kind of waiting-room and other accommodation necessary.

Heating and lighting.

5. Whether *Fires or stoves* will be required in the rooms or offices; if so, what kind are usual in the country, and what the kind of fuel. The method of *Lighting.*

Climate.

6. Information concerning the *Climate*, building materials, transport, water-supply and drains.

Goods traffic.

If provision has to be made for *Goods* traffic, or a goods-station is required, the following additional information must be supplied.

Number of trains.

7. The number of goods or mineral *Trains* expected to stop at the station, and the approximate number of wagons, distinguishing between inwards and outwards traffic, so as to show which predominates.

Kind and weight of goods.

8. The nature of the *Merchandise* sent from or to the station, and the weight of the heaviest pieces, so far as will determine the kind of buildings and cranes which will be required.

Marshalling of trains.

9. Whether much *Shunting or marshalling* will take place either of trains or wagons, and what siding accommodation will be necessary.

Workshops.

Railway Workshops are required principally for the repairs of locomotives and rolling-stock, and also for work connected with the permanent-way and signals. Economy both in the first cost and in the current expenditure in the workshops afterwards, depends to a large extent on the proper arrangement of the buildings and machinery at the commencement. It is sometimes convenient to adopt a standard size and form of roof for all the sheds on the railway, roofing made in squares of 20 ft. or 40 ft. being supplied, so that any number may be combined for any site. The roof principals may be made with advantage of the "saw" or "weaving-shed" shape, with a north light and ventilation. Some or all of the stanchions or columns should be suitable for attaching small lifting-cranes, brackets for carrying shafting, and sometimes even for drilling-machines. The extent and the arrangement of

Arrangement of buildings.

Roofs. *See page* 869.

Columns. *See* FACTORIES, *page* 477.

Subdivision of processes.

Workshops must be complete.
See also page 408.

Foundry.

See Chap. XXV. MACHINE TOOLS.

workshops must be decided primarily by the length of railway and the amount of traffic to be provided for; and the greater the scale on which the workshops have to be built, the greater will be the number of subdivisions that may be advantageously made for different processes. In colonies and places where private factories are not available for the ready purchase of materials and fittings, the railway workshop must be complete in a way not necessary in manufacturing countries. Thus a small melting cupola with blower, and a brass foundry should be established at the outset. On the other hand, in designing workshops for a small railway, the methods which obtain in larger shops, or on more important railways, should not be imitated, as special tools and systems which may be applicable in the one case, but which involve considerable outlay at the commencement, will be quite out of place in the smaller one. Not only have new tools and automatic processes been invented for locomotive work, but lathes and other machines common to all engineering factories are adapted to special operations of detail, the need for which repeats itself so regularly as to keep machinery and men constantly employed. Thus, while in a small workshop the same wheel-lathes may serve for the very different work of turning large driving-wheels and small wagon wheels, in a large workshop separate lathes are set apart for each of these duties. Besides the ordinary lathes, drilling-machines and other tools usual in all engineering and boiler factories (and described in another chapter), the following may be enumerated as special to a railway workshop:—

Special tools for locomotives.

Wheel-lathes; tire-boring machines; tire-blocking and stretching machines; lathes for the crank-axles of engines with inside cylinders; lathes for wagon and plain axles; crank-pin boring or quartering machines; multiple drills for tube plates; wheel-rim drilling machines; wheel-rim shaping machines; key-way drilling machines; hydraulic presses for forcing wheels on and off their axles; cylinder-boring machines for a pair of cylinders; sheer-legs for lifting locomotives off their wheels; hydrants for washing out the engines.

Ordinary lathes may suffice.
See LATHES, *page* 737.

Of the above, which are all fixed machines, some may be dispensed with in a small factory. Thus, there is no need to devote lathes specially to turning axles or boring cylinders, as an ordinary 12-in. screw-cutting lathe may serve for both these purposes; so also, tires may be bored out on the chuck of a wheel-lathe instead of on a special machine; crank-pin boring-machines may be dispensed with; one wheel-lathe may suffice, if made large enough for the largest kind of wheel, or even an ordinary gap lathe, useful for other purposes, may be sufficient. Besides the fixed machines, numerous *portable* machine-tools have been devised, which can be affixed to the work instead of detaching the pieces to be operated on from the locomotive and bringing them to the machine; the use of such machines allowing great economy in time and money. Thus, there are tapping-machines for the stays of fire-boxes, machines for cutting key-ways in eccentrics, and machines for re-boring cylinders while in their places. Other special appliances are being introduced into large locomotive work shops. Among these are hydraulic or other machines for testing springs; weighing machines for ascertaining the distribution of weight on the various axles; powerful travelling-cranes for lifting locomotives entire, and carrying them from one part of the shop to the other. Such cranes may render unnecessary the sheers above referred to.

Portable machine-tools.

Special appliances.

See CRANES, *page* 787.

It is obvious that the extent to which the above tools can be adopted in any particular workshop, depends on the kind and amount of work to be done, and on the amount of capital available for it. Repairing-shops for a small railway employing only six locomotives and 100 vehicles would, if built in England, cost from £10,000 to £15,000, including machinery and tools, but £8000 will generally suffice at the commencement. From this upwards there is hardly any limit; the outlay on some of the establishments for the principal English railways approaching a million sterling. Indeed, there is on some railways a tendency to create manufacturing establishments unduly large, which absorb much of the capital and management which should be devoted to the primary purpose of carrying traffic.

Capital outlay.

Sometimes excessive.

Although one repairing-shop may suffice for a considerable length of railway, "running-sheds" are required wherever engines have to be sheltered; and it is usual to provide in such sheds water under pressure and stand-pipes for washing out the boilers, a furnace for drying sand, stores for such articles as gauge-glasses, piston-rings, and small parts often required, as well as for coal, oil, tallow, and waste. How far other tools may be added, such as a small lathe, or smithy fire, depends on the distance from the repairing-shops and the likelihood of sudden local repairs being required. It is of course convenient to have a coal-stage and water-tank near to the running-shed. It is often also necessary or expedient, if there are no suitable houses near at hand, to provide dwellings for the foremen, engine-drivers, and others, so that they may be quickly summoned, and saved a long walk before and after working hours.

Running sheds.

Stores.

See page 681.

Workmen's houses.

See also page 880

Information necessary.

The following information is necessary as a basis for planning railway workshops and for selecting the most suitable tools.

Extent of railway.

1. The *Length of the railway* to be served by the workshops: whether a single or double line; the gauge of the railway and the number of train-miles run.

Number and kind of engines.

2. The *Number of locomotives* on the railway, with a description of each type, including the weight and diameter of the largest wheel; and the approximate number in detail of each different kind of carriage or wagon.

Plan and section of site.

Foundations.

3. A *Plan and section of the Land* available for the workshops, showing the railway and the positions of the stations, buildings, and sidings, and the road approaches. The likelihood of complaints of nuisance from the smoke caused by the engines. The nature of the soil, and its suitability for foundations; the direction and system of the drainage.

Materials.

See page 74.

4. The *Building materials* available, the climate, and other local information as already described.

Nature and extent of work to be done.

Making wagons or repairing only.

See pages 408, 451 & 592.

5. The nature and extent of *The work to be done*: for instance, whether locomotives are to be made as well as repaired; whether carriages and trucks are to be made, and if so, whether everything will be done in the local workshops, or the ironwork imported. When a railway is thoroughly established, it may be advantageous to make wagons, so as to save the cost of carriage from a manufactory, and to find employment for workmen whose primary duty may be in repairs. But it is seldom expedient to make other ironwork than the simplest forgings. Springs, buffers, and minor fittings are hardly ever made in railway workshops.

Timber.

6. The kind of *Timber* used for the carriages and wagons, and the condition (logs, sawn timber or planks) in which it will arrive at the factory.

Iron and brass foundry.

7. Whether an iron or brass *Foundry* is required, or whether the necessary castings can be purchased. Whether sand suitable for a foundry, or sand for the locomotive wheels, is obtainable.

Signals and permanent-way.

8. The kind of *Signals* used on the railway should be described, and anything special connected with the points or permanent-way which needs special repairs.

Fuel.

9. The kind of *Fuel* used on the locomotives and obtainable for the factory engine and smiths' fires.

Water supply.

See page 197.

10. The source of the *Water supply*, and the quality and pressure of the water; the number of engines per day to be washed

out or wanting water, and the capacity in gallons of the engine tanks.

Lighting. 11. The system of *Lighting* the workshops which is to be adopted, and whether gas-works or electric light apparatus are required.

Houses. 12. Whether houses or other living accommodation is wanted for any of the workmen, foremen, or staff, and if so, for how many.

Platelayers' tools. *Platelayers' tools* cost from £5 to £20 per set, and a proper selection depends on the following information:—

The extent of railway for which the tools are required; the amount of traffic, as indicated by the number of trains per day or the number of train-miles; the gauge of the railway, and the width of the "six-foot"; the system of permanent-way, describing the section and weight of the rails, and the mode of fastening and jointing them; the weight of the engines; the climate; and the kind of workmen employed.

Ramps by which engines and wagons may be replaced on the line after accidental derailment are now generally used on railways. They cost from £2 to £3 each, and weigh from 80 to 100 lbs., so that they may be carried on the engine or in the guard's carriage.

183.
Ramps.

[*See also* RAILWAYS : LOCOMOTIVES AND ROLLING STOCK : FACTORIES.]

CHAPTER XXIV.

RAILWAY EQUIPMENT (CONTINUED). LOCOMOTIVES AND ROLLING-STOCK.

Locomotives.

IN the design and equipment of a new railway, the *Locomotives* should be considered at an early stage of the proceedings; for if this be not done, and the railway be laid out, and the gradients, curves, and permanent-way settled, the locomotive engineer, when his time comes, will find that he has to carry the traffic under conditions which he might have improved if he had been consulted earlier. The gauge of the railway, the kind of rails, and the strength of the bridges, should in a large measure depend on the size and power necessary in the engines; but these essential points are often irrevocably determined before the locomotives are thought of. It is evident that a powerful engine—if such be required—is crippled if a narrow-gauge and light rail limit the size and accessibility of its working parts; while, on the other hand, a permanent-way may have been constructed unnecessarily wide or strong for the kind of locomotive which the gradients and traffic require.

Permanent-way must be suitable.

Choice of engine.

On every railway, the use of the most appropriate kind of train is an important factor in the economical working of the line; and, in conjunction with the gradients, it determines the power and class of engine that is required. Generally, heavy trains at slow speeds are preferable for mineral and through traffic, or where the movement is from one great centre to another, or where—as, for instance, in India or South America—fuel and wages are dear while time is cheap. On the other hand, where the traffic is chiefly local, or consists of passengers or perishable goods, lighter trains, running at more frequent intervals, are required by the community, and are essential to profitable management.

Weight and speed of trains.

Tractive force depends on adhesion.

The tractive power of a locomotive depends, not only on the force exerted by the steam on the pistons, but on the adhesion of the engine upon the rails, and therefore on the condition of the rails. The greatest adhesion is obtained when the rails are quite dry or very wet; the maximum under such circumstances being about one-fourth the insistent weight on the driving wheels of the engine, including in this weight that on all the wheels coupled to those which receive the power from the piston-rods. As an example, if the driving-wheels of the engine press with a weight of 20 tons on the rails, a tractive force of 5 tons may be exerted; though this maximum is obtainable only under favourable circumstances. One-sixth is a fair average; while one-tenth, or about 224 lbs. for each ton weight, may be considered the minimum. The last is an extreme case, which occurs only when the rails have become very slippery in damp, foggy, frosty, or snowy weather. In such cases, if the train-load exceeds what this reduced adhesion will draw, the driving-wheels, instead of advancing, will slip round, but the slipperiness may not only be to a considerable extent counteracted by the sprinkling of dry sand on the rails, but still more neutralised by the modern introduction of the sand-blast. In hot, dry countries the wheels seldom slip; in England the slipperiness varies with the weather, and is often very great; while in certain seasons, or after dew-fall, in moist countries like the Mauritius and the west coast of South America, slipping can hardly be avoided by sand-pipes in front of each coupled wheel. With ordinary care and appliances a coefficient of one-sixth can be obtained even under unfavourable circumstances, and very often one-fourth.

Insistent weight on driving wheels.

Slippery rails.

Influence of climate.

Steam sanding.

On a level, well-laid road, engines can draw very heavy loads, as the only resistance then to be overcome are the friction of the axles in their bearings, the wheels on the rails, and the resistance of the air or wind. But resistance often seems to vary unaccountably under precisely similar conditions. On the best British lines, where the permanent-way and the rolling-stock are in good condition, the total from these causes is so slight that the resistance to haulage of a passenger train, when running on a level track at 15 miles an hour, is only from 3 to 6 lbs. per ton weight of train (though about treble this force is necessary to start a train); but the resistance, owing to oscillation and greater air pressure, increases with the speed, so that at 40 miles an hour the resistance would be from 10 to 18 lbs. per ton. The higher speed therefore involves a greater expenditure of steam, and consequent consumption of fuel. The maximum speed which can be attained obviously

Haulage force.

Train resistance.

Increases with speed.

Maximum speed.

Average speed.

Haulage of goods trains.

depends on the condition of the road and rolling-stock, so that, while on the best English lines passenger trains maintaining an average speed of 50 miles an hour sometimes run for short distances at the rate of 75 or even 80 miles an hour, the maximum speed attainable with the same tractive force on less perfect lines would be much less. If the rails be badly laid or much worn, or the rolling-stock be in bad condition, the friction is increased, and instead of 3 or 6 lbs. per ton, the resistance and haulage, even of a passenger train at a slow speed, would be 10 lbs. or more; and in countries where the railways have been too cheaply or hastily constructed, or are badly maintained, the resistance is still greater and the expenses of haulage are very high. The resistance to haulage of a goods train, when moving at a speed of from 15 to 20 miles an hour, ranges, on a well-laid line, from 8 to 16 lbs. per ton weight of train.

Gradients.

Gravity resistance.

See pages 63 *&* 301.

Incline of 1 in 100 trebles resistance.

Examples!

Steep gradients to be avoided.

See page 63.

It is, however, the maximum or ruling gradient of a railway which mainly determines the power necessary in the engine, and if railways could only be made level, engines might be much smaller and lighter than they are, or the trains much heavier. In ascending an incline, the gravity of the train has to be overcome; and in this respect, a train on a railway has no advantage over a vehicle on an ordinary road. As has already been described, the dead weight of the train has to be lifted, so that a gradient of even 1 in 100 adds one-hundredth part of a ton, or 22½ lbs. to the haulage force required for each ton weight of a train. Thus, if 10 lbs. be sufficient for the haulage of each ton on a level, the resistance is more than trebled. A gradient of 1 in 50 would add 45 lbs. to the 10 lbs., and so on. As an example, a locomotive weighing 30 tons, and having an insistent weight on the coupled wheels of 20 tons, will have, reckoning only one-sixth of the weight (which is a moderate estimate) a tractive force of 7467 lbs., and at the rate of 10 lbs. haulage resistance per ton of load, will draw on a level track a train of 746 tons exclusive of the engine. But on an incline of 1 in 200 the resistance is 21¼ lbs. instead of 10 lbs., and the engine will draw only 321 tons; on a gradient of 1 in 100, 200 tons; on one of 1 in 50, 106 tons; and on 1 in 20 only 31 tons. But on steep inclines it is usual to so couple all the wheels as to utilise all the weight of the engine for adhesion. If the whole 30 tons were thus utilised it could draw 62 tons. It is because of the reduction of haulage capacity which takes place on steep gradients as above described, that considerable expense in cuttings, tunnels, and embankments is incurred in order to

Extra capital cost repaid by cheaper haulage.

Maximum gradients.

Special engines.

Risks in descent.

Centre rail.

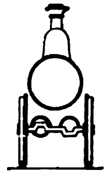
Toothed wheels.

Fixed engines. *See also page* 317.

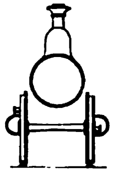
make a railway as level as possible. The greater the traffic expected, the more justification is there for such expenditure, as the saving in haulage outweighs the interest on the extra capital expended. But the necessity or desire for cheap first cost, which often leads to the use of steep gradients in the construction of railways, involves expense in other ways. The engines, in order to have adhesive force to overcome the greater resistance, must be made heavier than for level roads; the rails must therefore be stronger and more expensive; and the expenses of fuel and maintenance are increased. These circumstances, and the disadvantages above described, are not always sufficiently appreciated when it is attempted to economise in construction. Gradients steeper than 1 in 100 seldom occur on English main lines, but where the advantages of railway communication are not otherwise attainable, much steeper gradients may be surmounted. An incline of 1 in 20 is seldom met with, and is still more rarely exceeded by trains drawn or pushed by ordinary locomotives; but by special contrivances even steeper inclines may be overcome. The objections to very steep gradients lie in the descent as well as in the ascent, and although locomotives have been made to haul (with no other grip on the rails than their adhesion-weight affords) loads up gradients as steep as 1 in 15, no system of brake-power by which merely the gravity weight of the engine skidding on the rails is made effective, would render the descent of such a gradient safe with a load as great as the engine could haul up. And unless the road be in good condition, a gradient of 1 in 20 would in the same way be dangerous. On the railway over Mont Cenis, in operation before the tunnel was completed, the "Fell" system of a centre rail was successful on gradients as steep as 1 in 12. The centre rail, with wheels pressing sideways upon it, was as necessary for safety in descent as for power in ascent. The more modern method adopted on the Rhigi, the Zermatt, and other mountain railways in Switzerland, where there are gradients as steep as 1 in 5, is that by which toothed wheels upon the engine work into steel racks laid between the rails. There is also the plan for still steeper gradients (available also, of course, for vertical loads) of a fixed winding-engine hauling the carriages by a wire rope, as is usual in and about mines.

Classification of locomotives.

Locomotives differ so variously that they can only be classified broadly according to some of their leading features. The position of the cylinders, inside or outside the framing, is one important point of difference, and engines may be divided into two classes accordingly.



184.
Inside cylinders.



185.
Outside cylinders.

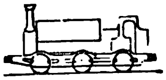
Inside cylinders are generally preferred in Great Britain and on the broad-gauge lines in India, while outside cylinders are almost universal in the colonies, and on the Continent and in the United States. Inside cylinders require the use of a crank-axle, and crowd the working parts of the engine so as to render them less accessible than when the cylinders are farther apart. On the other hand, engines with inside cylinders are lighter, and allow of certain economies in manufacture. Another reason for their use in England has been that the leading axle can be placed under or very near the cylinders. This is especially convenient with the usual type of English goods-engine, where the six wheels are all coupled, for the weight on the leading wheels would be excessive were outside cylinders used. But the use of a bogie or radiating axle at the front end of the engine overcomes these objections, and not only gives a flexible wheel base, but allows outside cylinders to be used with a good distribution of weight on the wheels. This conduces to smooth running on a rough road. For the high speeds usual in England, the supposed greater steadiness when the engine is running, the compactness of parts, and the less wear on the driving axle-boxes, are also arguments in favour of inside cylinders; but in countries where slow speeds are usual, any unsteadiness caused by outside cylinders is of less consequence.

Steadiness in running.

Another classification of engines is that according to the mode of carrying fuel and water, the arrangements for this being determined mainly by the distance apart of the sources of water supply, and by the distance to be run without stopping. *Tender-engines* are generally used for through trains, but the large tenders necessary in crossing arid plains or deserts where no water is met with for 50 or even 100 miles, are unnecessary in trains stopping more frequently, and tenders are made to suit the service required. In England, trains run 130 miles without stopping, and without access to water troughs laid between the rails for supplying the engine while running. But this is only possible where the easy gradients and the weight of train limit the power and quantity of water required. A *Tank-engine* has no separate tender, but carries its water either in a tank on the boiler or on each side of it, and the fuel in bunkers behind or on each side of the foot-plate; the position of the water and fuel being determined by what is necessary to a proper distribution of the load upon the different wheels. If carefully designed in these respects, and well made, a tank-engine will run steadily, and, on a steep incline, will haul a greater paying load than a tender engine of similar cylinder

Tender-engines.

Carriage of fuel and water.



186.
Tank-engines.

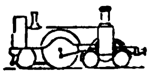
Useful on steep inclines.

As compared with tender engines.

Limits of distance.

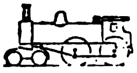
Maximum weight of tank-engines. *See* BRIDGES, *page* 149.

power, but with less adhesion weight on the rails (all the wheels of the engine being in either case rendered effective by coupling), because in the latter case, as the tender has to be hauled, its weight is included in that of the train, while in a tank-engine the load of fuel and water is effective as adhesion-weight and the haulage force is all available for the train. On narrow-gauge railways with light rails these circumstances are in favour of a tank-engine for steep inclines. Tank-engines are preferable for short runs, branch lines, shunting at stations, and for contractors' purposes; but they cannot carry sufficient fuel for long runs, and the side tanks, especially on narrow-gauge lines, render them unsteady at quick speeds or on uneven roads. Moreover, there is for any but very strongly-made railways a limit of size to these engines, because if made with boilers and cylinders of large capacity, the additional weight of water-tanks and fuel on a short wheel-base imposes too great a load on the rails and bridges. But very powerful tank-engines are occasionally used, the heaviest having a load of 16 tons on each of three pairs of wheels, or a total of 48 tons on a wheel-base of 16 ft. Engines of this kind strain small bridges more than the heaviest tender engines, and the strength of the permanent-way and bridges should be considered before such an engine is chosen. On the South African railways which cross arid hilly ranges, considerable adhesion and large water capacity are necessary, and therefore tank-engines, having also separate tenders, are used.



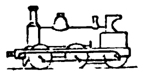
187.

Single engine.



188.

Four-wheel-coupled engines.



189.

Six-wheel-coupled engines.

See also page 698.

Another classification of engines may be made according to the coupling of the wheels. By coupling one or more pairs of wheels to the pair on the crank or driving-axle, the adhesion weight on all the wheels so coupled is rendered effective. Thus, there are "single" engines, in which the driving-wheels are not coupled on to the other axles, and only the weight on the one pair of driving-wheels is effective for adhesion; "four-wheel-coupled" engines, in which two axles or pairs of wheels are connected together; "six-coupled" engines, with three pairs of wheels coupled; and finally, "eight-coupled" engines with four pairs of wheels coupled. For passenger trains on easy gradients where a high speed is required, an engine with one pair of driving-wheels is sometimes used, because, while the weight on one pair of wheels affords sufficient adhesion for a light load, the arrangement is favourable to quick running. Single engines will draw considerable loads on well-laid lines, and even gradients as steep as 1 in 100 do not hinder their use. When once a speed of 30 miles an hour is attained, these engines compare favourably with coupled engines; but while they may be thus sufficient for long runs without stopping, it is difficult with them to start promptly, especially if on an incline or on slippery rails, and they are therefore unsuitable where such circumstances are likely to occur. Moreover, with increasing traffic and heavier rolling stock the weight of trains has tended to increase, and the concentration on one pair of wheels of the load necessary for adhesion is trying to the permanent-way and bridges on any but strongly-made lines. Their use, which is almost entirely confined to a few lines in Great Britain and France, is encouraged by the use of heavier and stronger steel rails than formerly, and by the introduction of steam sanding before referred to, which even in windy weather secures a good supply of sand, and thus enables the maximum adhesion to be maintained under adverse circumstances. Though it is found that four-coupled engines are sufficient for speeds up to 50 miles an hour, and, under favourable conditions, even for 60 miles an hour, single engines are undoubtedly best for light trains running at high speed on a level railway. The risk of coupling-rods breaking, which is often a cause of accident, is of course avoided by the use of single engines, which have no coupling-rods. Four-wheel-coupled engines are usual for ordinary passenger trains and light, quickly-running goods trains on easy gradients, but for general goods traffic three pairs of wheels are coupled. It is not that engines with two pairs coupled are insufficient when once in motion, but they are often unequal to the starting of heavy trains, and therefore are not suitable where much shunting is required. The coupling of more than three pairs of wheels is seldom exceeded in Great Britain, but on the Continent and on some lines in the United States, where heavy goods trains are taken over permanent-ways not strong enough for great adhesion-weights concentrated on a few wheels, four, and in rare cases more, pairs of wheels are coupled together. In the distribution of weight on the wheels, and in arranging the total weight of engine and tender on a wheel-base of certain length, the sufficiency of the permanent-way and bridges to sustain such loads without injury is an important point to be considered.

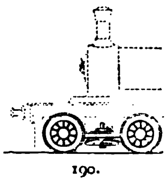
Disadvantages of single engines.

Steam sanding.
See page 692.

Quick light trains.

Eight-wheel-coupled engines.
See page 149.

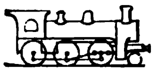
Where there are curves on the railway of less radius than 20 chains (1320 ft.) it is advisable to use engines with a flexible wheel base. Such engines are known as *Bogie-engines*, a "bogie" or frame with lateral and swivelling motion carried by four wheels being placed



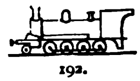
190.

Bogie-engines.

under either end of the engine. Such an arrangement is applied to the engines shown in Figs. 191 and 192, where, as is generally the case, the bogie is placed under the cylinders. A single pair of radiating wheels, often termed a "pony" truck, can be applied in a similar manner, and fulfils the same object, guiding the engine round curves, and reducing the resistance and the wear of tires and wheels. When a pony truck is used with six coupled wheels, the engine is termed a "Mogul," and where with eight coupled wheels, a "Consolidation." In a "double-ender" a pony truck is used at each end of the engine, which is thus equally flexible whether running backwards or forwards. Although bogie engines were at an early date made in England, locomotives of the ordinary kind continued to be exported for use even on railways where the road and curves were unsuited for their use. Bogie engines for meeting the difficulty were first made on a considerable scale in the United States, and have since been widely adopted in Europe and elsewhere.



191.
Mogul.



192.
Consolidation.

Tubes and tires.
See pages 559, 575 & 657.

Fuel consumption depends on skill of driver.

Consumption per train-mile.

On most railways fuel, tubes, and tires form the three main items on which the expenses of wear and tear in running are incurred. Various points in the design of a locomotive depend on the kind of fuel to be used. Almost every kind of coal can be burnt, but the firebox, grate, tubes, blast-pipe, and other parts have to be specially arranged to suit the kind of fuel to be used. The generation of steam, and the maintenance of sufficient pressure, depend on the skill of the driver and fireman, who should attain these objects with the least possible expenditure of fuel, an important item in the economy of railway working. On English railways the consumption of coal ranges from 2½ lbs. to 4 lbs. per indicated horse-power per hour, but much of course depends on the quality of the coal. For passenger trains the consumption per mile ranges from 15 lbs. for light trains at moderate speeds to 35 lbs. for heavy trains, and even this is exceeded for trains which have to stop very frequently. For goods trains the consumption varies from 35 lbs. for light express goods trains to 50 lbs. for heavy mineral trains. But it is not easy to reckon coal according to mileage, because much coal is consumed while the engine is standing idle or shunting; but, on the other hand, this unit of consumption is convenient to railway managers, and is more frequently adopted than the more scientific plan of measuring the coal according to the quantity of water evaporated per passenger per mile or per ton hauled per mile. It is generally attempted, by supervision and a system of rewards, to give to the men

Wood fuel. **Spark arresters.** **Cow-catchers.**

engaged a share in the saving below a fixed standard of consumption. Wood fuel requires a sharp blast to promote consumption, and produces abundant sparks, which, to prevent the ignition of herbage or trees, or even the train itself, must be consumed or stopped in the chimney by a suitable contrivance. In Europe, railways are almost always fenced in from the surrounding land; but in countries where this expense is avoided, the engines must be provided with cow-catchers or pilots for clearing the track of straying cattle or wild animals.

Large cylinders. **Boilers.** **Steam pressure.** *See also page* 580. **Pressure on piston.** **Piston speed.**

Most of the improvements which have been made in locomotives since 1860 are applicable to all the types just described. Greater power than formerly is obtained; and by a compact arrangement of parts, cylinders of 18 in. and even 19 in. diameter are placed without inconvenience within the framing of standard-gauge engines, the increased piston area so obtained being very considerable. Improved boilers and fire-boxes facilitate rapid combustion and the generation of sufficient steam for such large cylinders. As boiler space is limited on a locomotive, it has been sought to increase the power by higher pressures of steam, but there are certain difficulties which limit any great alteration in this respect. From 130 lbs. to 150 lbs. per square inch are usual working pressures in England, and on a few railways 160 lbs. is customary. On some foreign railways 180 lbs. prevails, while the pressure customary in other kinds of land steam-engines seldom exceeds 120 lbs. The maximum average pressure on the piston for a sustained effort, such as in surmounting a long incline, is from three-fifths to three-fourths of the boiler pressure; for a short distance, or at starting, 85 per cent.; while, at full speed only about one-third of the boiler pressure can be reckoned on. The highest piston-speed ranges from about 500 ft. per minute for a goods-train engine at 20 miles an hour, to about 1000 ft. per minute for an express passenger-engine running at 60 miles an hour.

Compound engines. **As tried in England and United States.**

The most striking departure from ordinary practice has been the application of the compound principle to locomotives, where it is sought to obtain the economy and other advantages, proved in the case of marine engines, of allowing the high-pressure steam to expand in two or more cylinders in succession, whereas in ordinary steam-engines it is begun and ended in one cylinder. Various methods of carrying out this idea have been tried in England and the United States. In some cases one large cylinder has been added, and in

Not yet widely adopted.

other cases two cylinders. The different systems of inside and outside cylinders which obtain in the two countries, and a due regard to the balancing of the engine, have affected the solution of the question in each case. Up till 1898, although probably more than 300 engines on the compound principle were in use, the advantages claimed had not led to any wide or general adoption of it. One difficulty of applying the principle arises from the fact that locomotives, unlike most other engines, have to exert full power at starting, and this full power is not in all cases immediately available when the steam is admitted to the high-pressure cylinders.

Steam brakes.
See page 707.

Continuous air brakes.

Steam brakes have been extensively adopted for goods-engines, and are found of great use in giving to a driver more control over his train; they also allow considerable saving in time in shunting. Continuous brakes, most of which are worked from the engine by the driver, and which are used on all important passenger trains, are also used to great advantage on goods trains in some of the British colonies where the gradients are long and severe. Where such brakes are applied to goods wagons as well as to passenger vehicles, mixed trains can be run at a higher speed than would be safe were the goods wagons fitted only with hand-brakes. The application of continuous brakes to long goods trains presents many difficulties, but is likely to become general.

Modern use of steel.
See page 559.

Improved boilers.

Fire-boxes.

Copper or steel.

Systematised manufacture.

While, as just described, the most conspicuous improvements have been in the direction of greater power and flexibility, various improvements in detail have been made in order to render the locomotive more durable. Steel is used for boilers, tires, axles, wheels, slide-bars, piston-rods, coupling-rods and other important parts, but it has not generally been found so effective as brass for tubes, or so trustworthy as copper for fire-boxes, its use for this purpose being almost exclusively confined to engines made in the United States. While steel is cheaper than copper, and is as durable where the water is perfectly soft or nearly pure, it is less durable with hard water, and on some railways it is deemed necessary or expedient to soften the water artificially before supplying it to the tender. Increased area and better lubrication have been given to bearing surfaces; boilers have increased water-space, stronger seams and stays; and these with steam or hydraulic riveting, have together tended to increased durability and to a lessened cost of repairs. A more systematic method of manufacture, subdivision of labour, and the use of special machine-tools, have together reduced cost, and at the same time improved the quality of the workmanship. A good system of working to gauges and templates ensures similar parts on different engines being exactly alike or duplicates of one another, a great convenience in repairs. In British-made locomotives a handsome appearance is sought rather by the just proportioning of parts, symmetrical outlines, and graceful curves, none of which involve extra cost, than by unnecessary paint and ornamental brass-work, which are frequently a cover for bad design, workmanship, or material. The simpler designs are compatible with that good appearance of the engine which induces pride and care in the engine-driver.

Simplicity of design.

Defects in locomotives.

Locomotives are complex and hard-worked machines, and defects, whether in materials or workmanship, soon betray themselves in some slight or serious accident, causing delays on the road, or general inefficiency. The time and money expended in repairs and renewals from these defects are, especially in countries distant from the place of manufacture, very great; and it is obviously important to ensure by correct and simple design, by the employment of capable manufacturers, and by proper supervision, that the most suitable engines shall be obtained. If these precautions are neglected, or a supposed cheapness allowed to prevail, cause and effect will probably be exhibited in some of the following ways:—If brass of inferior quality has been used, the bearings become heated and the valves wear out; tires too soft become loose, wear hollow, cut their flanges, and require re-turning; tires too hard are liable to fracture at high speeds; the link-motion, if not well hardened and properly hung, soon wears loose, rattles, and gives an extravagant and unequal distribution of steam to the cylinders; while the cylinders, if of soft or inferior metal, will soon become so worn as to require re-boring and re-facing. Such are a few examples of defects in the wearing parts, and results even more serious occur if the boiler be badly made. Bad caulking, or rivet-holes which are not properly filled by the rivets, soon reveal themselves; imperfect tubes become leaky, or burst during work, causing an annoying stoppage; while a fire-box made of inferior copper cracks and wears thin, necessitating renewal.

Involve trouble and expense.

Examples of defective parts.

Defective boilers.

In England the quicker speeds and the greater traffic than those of foreign railways have led to a high standard of excellence in these respects, which has been followed in the engines made in Great Britain for Indian, colonial, and foreign railways. In Europe also such engines stand pre-eminent, but in America, owing to many different circumstances, other types of engines and methods of con-

High standard of excellence in English engines.

struction have prevailed; and engines made in the United States have been preferred on some railways formerly supplied from England, partly because of their supposed greater suitability to the roads and partly from lower first cost.

American engines.

Cheapness, how obtained.

Chilled cast-iron wheels.

See also page 718.

Cost of fuel and repairs must be reckoned.

A less cost is allowed by the use of thinner boilers (which restricts the pressure of steam), thinner wheel-tires, steel fire-boxes instead of copper, iron tubes instead of brass, lighter framing, cast-iron wheels, and the cheapening of various minor details. Both in England and America the driving-wheels have steel tires: but in England all the wheels of the engine have their centres or skeletons of forged iron or cast steel, while in America cast iron at one-fourth the cost has been generally used, and as there are about three tons of such wheels in one engine, the saving is very great. The wheels of the engine other than the driving wheels are, in America, generally made of solid chilled cast iron, without separate tires; and these wheels are harder than steel, but their life ends when the chilled part is worn through; they are not so trustworthy, and, not having been turned in a lathe, are not so truly formed. The use of steel tires on wheels is, however, extending on American railways. Unless the amount of fuel consumed, and the cost and inconvenience of repairs and renewals over a long term of years be taken into account, a low first cost is no criterion of cheapness; and although it is sometimes difficult to separate expenses arising from an ill-kept road or peculiar methods of working from those caused by defect in the locomotive, it is necessary to analyse these circumstances and allot them to their proper causes before a fair comparison can be made.

American methods of manufacture.

Variety of type in England a cause of expense.

Differences in the methods of manufacture in England and the United States are caused also by other circumstances besides those referred to above. In England, not only do the types of engines differ to an extent beyond those prevailing on most railways abroad, but each succeeding engineer gives play to new individual predilections, and the types of engines are again multiplied. This mode of proceeding has its advantages and drawbacks. Assuming capacity in the engineer, no one can better appreciate the exigencies of traffic or the peculiarities of the railway than he who has to meet them, and on whom fall all the trouble of repairs and the responsibility for accident: and as no two railways are exactly alike in all the conditions of permanent-way, curves, gradients, rolling-stock, and traffic, it is an advantage on each railway to have locomotives specially adapted to their purpose. But there is the disadvantage that so long as differences are demanded for every separate railway, no standard types of engines can be arrived at, nor can the cheapness in manufacture, which exact repetition allows, be obtained. In the earlier days of railways, however, there were few engineers who could design locomotives, and few manufacturers with experience to make them; and on the home and foreign railways supplied from England, the types of the leading makers were accepted without question. And while in Europe this system has been superseded by that described above of locomotive superintendents choosing or designing the exact kind they want, the necessary knowledge has not in the United States so widely spread, and the designing of the engines has been generally left (as is the case also with bridges and other equipment) to the manufacturers, though on some of the leading American railways the engineers also design their own locomotives. But the majority of the engines are of types established by manufacturers, who, having thus a repetition assured to them, can make cheaply in the same way that portable engines are made in Great Britain. And in countries where money is scarce or the rate of interest high, cheap construction and low-priced engines may be an essential condition of railway enterprise; and the fact that a well-made road and an English engine will, by their greater durability, eventually prove cheapest, may be no inducement to their adoption. Each system has its advantages, but there is no common basis on which to make a comparison in price between British and American engines, and in either country, if the design of the other be presented, the price would be necessarily dearer than for engines of an accustomed kind.

Makers' types not now accepted in Europe.

As in America.

See page 595.

Cheap first cost.

A new design for a locomotive involves more expense than is generally known. A complete set of entirely new drawings for a locomotive will cost from £100 to £200, while the patterns and templates will add from £100 to £150 more, but existing drawings can generally be adapted for from £50 to £100. Purchasers of locomotives sometimes stipulate that a set of drawings and templates be supplied to them, so that they are not afterwards bound to purchase new engines of the same design from the same maker.

Cost of new design.

Drawings and templates.

Electric Locomotives are likely to take an important place in the future. Up till about the year 1896 they were used only for narrow-gauge railways in mines, the exceptions being in a few cases like that of the City and Southwark Underground Railway in London. It was an essential condition on that railway that the noxious vapours of an ordinary steam locomotive should be avoided, and the success in that

Electric locomotives.

See page 171.

On tunnel railways.

Compared with electric tramways.
Accumulators insufficient.
Trolly system available.
Of higher power than on tramways.
Free from restrictions.
See page 171.
Water-power as in Switzerland.
See page 694.

case led to the adoption of electricity also on the Central London and other tunnel railways in the metropolis. In comparing the service required in cases such as these, with the numerous precedents of electric motor-cars on town tramways, there are—whatever be the ultimate solution of the problem—certain main differences. First, electric accumulators, which have been successfully applied on some tramways, are quite inadequate for the heavier service of passenger trains on railways, and power transmitted from a stationary engine must be used. Secondly, electric motors on the scale usual on tram-cars supplied from such engines by the overhead trolly or the conduit system, must be considerably increased for trains weighing 150 or 200 tons. Thirdly, there is a compensating advantage in the haulage of railway trains, that many of the restrictions deemed necessary for the public safety on surface street lines in cities would not be enforced in tunnel railways, and therefore engineers might conveniently utilise electric currents of higher voltage than have been permitted on lines under municipal rules. If electric power prove successful on tunnel lines, it is likely to follow on ordinary railroads, experimental engines for such lines being already in use in 1898. The advantages and drawbacks of electricity have a different relation in countries where fuel is expensive and water-power abundant, as may be seen on the Swiss electric railways at Zermatt and elsewhere.

Choice of engine.
See pages 691 *&* 709.
Variety of kind, where useful.
Uniform type best for small railways.

The *Kind of Engine* best suited for any particular railway depends primarily on the road, the gradients, and the nature of the traffic; but these important considerations are mixed up with others which vary almost in every case. On a large or busy railway, where numerous locomotives are required, different kinds may be selected for each branch of service. Thus, there may be "single" engines (one pair of driving-wheels) for light, quickly-running passenger trains, four-wheeled-coupled engines for heavy passenger trains and fast goods trains, six-wheel-coupled engines for heavy goods trains, and tank-engines for local traffic and station or shunting work; while if on one section of the line there are steep gradients, specially constructed engines may be provided for this district alone. But on small railways, where but few engines are required, it is advisable to have them of a uniform type, capable of taking any of the trains over every part of the line. If this principle be adopted, the most difficult service on the railway will have to determine what type of engine shall be selected.

Parts interchangeable though engines differ.

But even where various types of engines may be required on the same railway, it may still be possible and advantageous to so arrange the designs of the engines as to have their important parts alike and interchangeable. Thus, the boilers, cylinders, valve-motion, springs, and axle-boxes may be identical, and the differences in power which are required may be obtained by varying the diameter of the wheels and the method of coupling them, and by alterations in the framing thus rendered necessary. But it is very difficult to ensure such uniformity of parts if engines are bought from different manufacturers.

Conditions of Purchase.

Specification.
See pages 413, 421 & 588.

Materials and principal dimensions.

To secure a good engine at a reasonable price the specification, while stringent on all essential points, should avoid arbitrary conditions on minor points, which cause extra trouble and expense to the manufacturer without any corresponding advantage to the purchaser. But whether furnished by the buyer or seller, the specification should describe the important parts of the engine, for without such a description it is impossible to measure or compare prices. The gauge, the type of engine, inside or outside cylinders, and the number of coupled wheels having been recited, the following points are usually enumerated:—The size of boiler, thickness and quality of plates, and mode of riveting; the heating surface in the fire-box, the material (copper, iron, or steel) of which it is made, and a description of the staying; the number, size, and kind of tubes; the diameter of the wheels and axles, and the material of which they and the wheel-tires are made; the kind of axle-boxes and their fittings; the size of the cylinders and the kind of pistons; the capacity of the water-tank and fuel space; the brake arrangements; and the kind, dimensions, and position in regard to the rails, of the buffer and draw-gear. It is customary to include in the price of the engine the various minor parts necessary to its working; but as different makers do not supply the same kind and number of accessories, they should be enumerated when the price is arranged. It is also usual to specify the methods of testing, painting, and packing, and to state the weight.

Accessory parts enumerated.
See also page 590.

Purchase for export.
See Chap. XVII.

When engines are bought for export to a country where skilled workmen are rare and repairs expensive, special precautions to render the engines durable and easy of repair can be taken that would not be expedient or economical for a railway where repairs are easy, and where spare engines are always available to take the place of those temporarily withdrawn from service. Thus the water-space

Parts made durable and easy to repair.

of the boiler may be made larger; and the bearing surfaces ample, with means of taking up the wear, even if these provisions entail the disadvantage of extra weight and increased first cost. The effective case-hardening of moving joints (a process often omitted or imperfectly performed) should be ensured; parts especially liable to wear and fracture should be provided in duplicate to an extent far beyond what would be proper in the country of manufacture; and the extra outlay so incurred considered as a prudent security against greater expense afterwards. Fire-bars, tubes, gauge-glasses, piston-rings, brasses for the connecting-rods and coupling-rods, and for the axle-boxes, are among the most important of the spare parts required. The list of such extra parts needs very careful consideration, and the value of the articles enumerated should be duly weighed in comparing the offers of different manufacturers.

Duplicate and spare parts.

See pages 451 *&* 590.

Prices of engines fluctuate.

See page 443.

British makers.

The current prices of locomotives fluctuate considerably, not only with the cost of labour and materials, but according to the demand. There are (1898) in Great Britain about a dozen manufacturers of locomotives who confine themselves almost entirely to this one branch of engineering, and in addition to these the principal railway companies make new locomotives, although few make all that they require. Many of the railway workshops, established principally for repairs, have outgrown their purpose, and the gigantic factories which have been erected for making engines and rolling-stock are of doubtful profit to the shareholders who own them. Having, however, been established, they are employed, much to the disadvantage of the private manufacturers, who could probably, with profit to themselves, supply engines cheaper if prices and costs were analysed. But while it is seldom that engines are made so cheaply in railway workshops as in private factories, the great advantage may be more readily obtained of having exact similarity and interchangeability of parts. During the ten years ending 1898, if extreme high or low fluctuations be excepted, the following were average prices:—A passenger or goods-engine and tender of the best modern kind, with cylinders 18 in. diameter, 26 in. stroke, equipped as usual on the principal British railways, has ranged in price from £2200 to £2800, and as the total weight of such an engine and tender (when empty) would be from 55 to 65 tons, it will be seen that the prices are equivalent to from £45 to £55 per ton. But although it may be convenient sometimes to compare values in this way, any such estimate needs qualification, and can only be approximate, for the cost of a tender

Railway workshops.

See page 689.

Not so cheap as private factories.

But allow similarity.

P.ices of engines.

Weight.

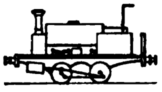
per ton is only about half that of an engine, and the proportion which the weight of the tender bears to that of the engine varies according to the kind of both. The above prices would embrace the average price of the best and most powerful kind made for European, Indian, and colonial railways. Powerful tank-engines, as used in England, sell for from £1900 to £2400, or, at a weight of 35 to 45 tons empty, equivalent to £45 to £60 per ton. The extra cost of fitting a continuous brake to an engine ranges from £80 to £120 for a tank-engine to from £120 to £150 for an engine and tender. A steam-brake can be similarly applied for from £50 to £70 less than these prices. In either case, the ordinary hand-brake can be worked independently of the continuous brake.

Prices of large tank-engines.

Extra cost of brakes.

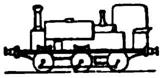
Contractors' locomotives.

The locomotives used by contractors in the construction of public works are almost invariably made as tank-engines, and as there are manufacturers who make a specialty of this class of engine, it is expedient to take advantage of the skill and experience by which the proportioning of the parts, the division of the weights on the wheels, and the balancing of the tank have been adapted to the purpose in view. A contractor's engine (for a 4 ft. 8½ in.-gauge railway) with outside cylinders 10 in. diameter, and with 4 wheels coupled, would cost about £900, would weigh about 11 tons empty and about 14 tons when equipped with coal and water. All the weight is effective for adhesion, but as the temporary roads used by contractors are uneven, and the wagons not usually in such good condition or so easy of haulage as ordinary rolling-stock, such engines when so employed can only be safely reckoned on for hauling 85 tons on a gradient of 1 in 100, or 45 on a gradient of 1 in 50. An engine with inside cylinders 12 in. diameter, and with 6 wheels coupled, would cost about £1200, and weigh about 14 tons when empty and about 17 tons when loaded. Such an engine would draw a load of about 140 tons of contractors' wagons on a gradient of 1 in 100, or 85 tons on a gradient 1 in 50. Heavier loads can, however, be hauled when the engines and wagons are kept in good order and the track is tolerably even. The tender-engines made in England for narrow-gauge railways (mètre, and 3 feet 6 in.-gauge) with cylinders of from 10 to 14 in. diameter, and weighing from 15 to 30 tons, have sold for £1100 to £1600 per engine and tender. Similar engines with side or saddle tank, and weighing from 11 to 20 tons, cost from £900 to £1400. Small locomotives, for railways of less



193.

Approximate power and prices.



194.

Narrow-gauge engines with tenders.

Little engines.
See page 68.

than a mètre gauge, cost from £400 for the little 2-ft. gauge, 5-in. cylinder engine weighing 2¼ tons; £600 for a 3-ft. gauge, 7-in. cylinder engine weighing 7 tons, to £1300 for the 3-ft. or mètre gauge engine weighing 15 tons. All the foregoing prices are exclusive of packing for export and of the cost of duplicate parts. Packing adds about 2 per cent. to the price, and duplicate parts add from 5 to 15 per cent., according to the quantity supplied, which, as has been said, should be determined mainly by the remoteness of the country and the difficulty there of renewing worn parts. A manufacturer requires from four to five months to make a locomotive from a new design, but those made of an established type can be made in from two to four months, according to size.

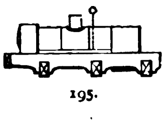
Cost of packing.
See page 447.

Testing of engines.

Stripped for shipment.

Weight of engines and cases.

Separation of parts.
See pages 451 & 591.



195.

Delivery alongside.
See page 442.

An engine, having been completed at the manufactory and made ready for the road, is tested under steam. The wheels having been raised from the ground, the engine is set to work, so that the tightness of the boiler, the efficient working of the injector and pipes, the smooth working of the motion, and the action of similar important parts, can be tried and defects observed. After having been examined and approved, the engine, if for export, is taken to pieces and all the fittings removed. The smaller parts of the engine are packed in cases, of which from 10 to 20 are required, according to the size of the engine and the weight in each case. The cases weigh from 10 to 20 cwt. each, but it is generally considered inexpedient to have more than 10 cwt. in any one case. Each axle with its pair of wheels upon it is shipped as one piece. The engine is thus stripped until nothing but boiler, cylinders, and frame remain together. This one piece or "body" generally forms about half the total weight of the engine when empty. If, however, this weight is difficult to deal with, either in transport or at the place of arrival, it can be reduced by removing the boiler from the frame; but this involves, of course, more labour in putting the engine together again than would otherwise be required. The finished surfaces and other vulnerable parts are protected, and baulks of wood on which the weight can rest are attached to the frame, generally by fixing them in the places of the axle-boxes. The "body" is lifted by chains passed under the boiler at the places (previously ascertained by experiment and marked) where the weight will be evenly suspended. The same careful adjustment of the lifting-chains is again necessary when the weight is lowered into the hold of a vessel and when landed at the port of arrival. Makers generally contract to deliver alongside the export vessel, and do not undertake the duty of placing on board. It is usual to paint the engine plainly, leaving decorative painting and varnishing to be done after the engine is re-erected.

Large hatchways.
See page 447.
See CRANES, *Chap. XXVII.*
Rates of freight.
See page 446.

On large modern steamers the hatchways are generally large enough to receive locomotives; but in some places very great trouble is caused, especially in unloading from the vessel, as at many foreign ports there are not the facilities which the powerful cranes in British ports afford. The space around the engine is generally packed with other goods, sometimes even with coal, if the parts liable to damage are protected against surface damage. On short voyages, in favourable seasons, locomotives are sometimes carried on deck; but in such cases a higher rate of insurance has to be paid. The cost of freight has always to be specially arranged, as the rates for ordinary machinery are never sufficient for the extra trouble and risk which are involved.

Choice or design, how determined.

To enable an engineer to design or select a locomotive suited to the purpose in view, he should be informed on the following points, an acquaintance with all of which are necessary to a proper choice:—

Gauge and permanent-way.

1. The *Gauge* of the railway; the section and weight of the rails; the kind of permanent-way, the distance apart of the sleepers and the condition, good or otherwise, in which it is kept. In addition to, or instead of, information concerning the condition of the permanent-way, a direction as to the maximum weight permitted on any one pair of wheels may be given.

Strength and headway of bridges.
See pages 137 *&* 166.
Loading gauge.
See page 711.
Couplings, turntables, sheds.

2. The strength of the under *Bridges*, not only in regard to the total load they will sustain within proper limits of safety, but also the fitness of the cross girders or other rail supports for sustaining a concentrated load on any point; the height and width of over-bridges and tunnels so far as these dimensions affect the height and width or "loading-gauge" of the engines passing under; the shape of *Couplings*, with their height from the rail level, and the height and width of *Buffers* in the existing engines and rolling-stock, to which conformity is necessary; the length of the turntables on the railway, and the standing *Space* available in the running-sheds.

Radius of curves.
Gradients.
See page 63.

3. The *Length of the railway*, the radius of the sharpest curve, and the inclination, length, and position of the steepest *Gradients*. The position of the gradients is important for various reasons. An ascent may be rendered less formidable by a descent immediately preceding

it; an ascent at or close to a station renders starting difficult; while a combination of the steepest gradient and sharpest curve also increases the power needed in the locomotive. A complete section of a railway showing the stations best supplies this information. The altitude of the railway above the sea (if it is high) should also be stated.

Weight and speed of trains.

4. The nature of the *Traffic*, and the maximum gross *Load*, exclusive of the engine, to be taken up the steepest incline. The average *Speed* of the trains.

Brakes.

If continuous *Brakes* are in use, or are required on the engine, their kind, and a diagram showing the exact position and length of the couplings on existing rolling-stock, stating whether the couplings are placed right or left of the centre when facing the engine. If the engine is for hauling goods trains, whether a steam-brake is required.

Fuel and water.
See page 681.

6. The kind of *Fuel* and *Water* available; the distance apart of the stations at which supplies can be obtained; and the distance which the engines will have to run without stopping.

Climate.
See also page 74.
Frost, snow, dirt.

7. The nature of the *Climate*, so far as it may cause rails to be slippery, or the occurrence of heavy snow-falls, or inclement or very hot weather, rendering special protection for the driver necessary. Much dust requires special coverings for bearings; while a tropical climate renders a cool and well-ventilated cab essential. Intense cold renders necessary special arrangements for oiling, and for draining the injectors and all pipes and cocks perfectly free of water; heavy snowfalls require snow-shields on the engine, and snow-ploughs or shovels. The rotary steam snow-shovels used in Canada and the United States are most effective, as they completely clear the track instead of merely ploughing a furrow.

Spark-arresters.

8. The nature of the crops, herbage, or trees by the railway, and the condition of the fences, so far as these circumstances may determine the need for spark-arresters and "cow-catchers."

Facilities for repairs.

9. The facilities for *Repairs* both in regard to workmen and workshops. The kind of engines already in use, the name of the maker, and the reasons, if any, for or against imitating them all or in part. Special defects or contingencies arising from local circumstances.

Transport.
See pages 445 & 708.

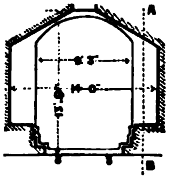
10. Such particulars as to destination and the means of *Transport* as may determine the method of subdivision and packing, as well as the probable cost of sea freight.

Rolling-stock.

See pages 64 & 691.

Rolling-stock is the general term by which locomotives, carriages, and wagons of whatever kind are classed, in distinction to the fixed equipment of the line; and locomotives have been described in the preceding pages. But just as the strength and dimensions of the permanent-way are to a large extent determined by the kind of locomotive which is to run upon it, so has the locomotive to be made suitable for the haulage of the trains; and therefore the kind of carriages and wagons which the traffic is likely to demand is a point to be considered at an early stage in the inception of a railway project. Of course, if the railway has already been made, or if there be not free scope for choice because of difficulties in the construction of the road, the process must to some extent be reversed, and these exigencies be held in view in designing the rolling-stock.

Carriages must accord with existing stock.



196.
Loading-gauge.

Established sizes.

Uniformity of parts.

Standard patterns.

If a railway be projected merely as a branch or extension of an existing line, or even if an entirely new railway be constructed in a district so supplied with railways that the new line will contribute only a small proportion to the general interchange of traffic, then the preference should be given to rolling stock similar to that already in use, unless there be very important reasons for alteration. Every railway has its standard "loading-gauge," indicating the dimensions which will allow safe passage through existing bridges, or past station platforms and cranes. The diagram shows such a loading-gauge of a kind customary on British railways, to represent the outline of maximum load and the outline of minimum structure for a single line, the dotted line A B showing the centre of the "six-foot," if there is a double line. It is obvious, therefore, that there are certain leading dimensions in rolling-stock which, when once established, become perpetuated, and can only be altered with great inconvenience. There must also be exact uniformity in the width between buffers, and in the height of the buffers and draw-hooks from the rails. And while conformity in these respects is absolutely essential, there are other details where uniformity is a great convenience; so that if, for instance, a spring, draw-bar, buffer, axle-box, wheel, or axle be damaged when the vehicle is on a neighbouring line, or far from its proper repairing-shop, a new part can be readily supplied and adjusted on the spot without delay. Subject to these considerations, it will generally be found expedient, for the saving of trouble and expense, to utilise existing patterns of those parts or fittings which are staple articles of manufacture. It is only in the case of railways in a new district or country that new designs and standard patterns for all the fittings and equipment can be established with advantage. In such cases existing designs should be adopted only when the circumstances are sufficiently similar, and the results have been proved by experience to be satisfactory.

Mixed trains.

In thinly populated countries it is seldom advisable to run trains exclusively either for passenger or goods traffic. "Mixed trains," composed partly of passenger carriages and partly of goods wagons, are therefore used, and where this is likely to occur the running gear of all vehicles, whether for goods or passengers, should be identical, and if continuous brakes are used, all the goods wagons should be fitted at least with pipes and couplings, so that continuous brakes may be used on the passenger vehicles, when as is usually the case, the goods wagons are placed nearest the engine.

Designing of rolling-stock.

In the designing of rolling-stock, the principal points to be borne in mind are those which promote the safe and cheap working of the traffic; and cheapness in the purchase price should be sought only when these more important conditions are ensured. The apparent saving by low prices may be soon out-weighed by the delays, repairs, and damages to goods caused by unsuitable or badly constructed rolling-stock. The points of principal importance are as follows:—

Uniformity.

1. The vehicles should conform to the *Loading-gauge* and station platforms, and, within the limits thus allowed, should be of suitable form and dimensions for the passengers or merchandise to be carried, and should require the minimum of labour in marshalling, loading, and unloading.

Capacity.

2. The vehicles should carry the *Maximum load*, and stand the shocks and strains of running and shunting without undue wear or distortion, and at a minimum cost for repairs.

Running gear.

3. The *Running gear* should be so arranged that curves can be traversed easily and the weight be moderate and equally distributed between the wheels. The vehicles should run smoothly and without hot journals at the usual maximum speeds. The cost of haulage, as well as of repairs to permanent-way and running gear, can be materially reduced by attention to these points.

Couplings and brakes.

4. The *Couplings and brakes* should be easily worked and be efficient under the most trying circumstances, so as to prevent accidents, especially in shunting and on heavy gradients.

Materials.

5. The *Materials* used should be durable, and suitable for the climate and traffic, with a minimum outlay for painting and renewal.

6. The corresponding parts of the vehicles should be, as far as

possible, *Interchangeable*, and all parts should be easily accessible for examination, repair, and renewal.

Parts interchangeable.

7. Passenger-cars and *Carriages* should allow of passengers entering and leaving with ease and safety; and the comfort of the seats, the ventilation, the method of lighting, and protection from extreme heat and cold, as well as from noise and vibration, should be carefully studied.

Lighting and warming.

8. The *Wagons* should be specially designed to protect the goods from the weather, from theft, and from loss and damage by concussion, abrasion, or leakage. The wagons should also be suitable for carrying a great variety of freight, and strong enough to stand the impact of rough freight during the shocks in shunting.

Strength of wagons.

The above somewhat conflicting conditions have to be considered together, and, according to the circumstances of each particular case, certain points must be subordinated to others of more importance.

It is only, however, by giving full weight to the various exigencies of the case, and by full accord between the traffic manager, locomotive engineer and permanent-way engineer, that the most suitable designs can be arrived at.

Accord between departments.
See page 659.

In the designing of *Carriages* for the conveyance of passengers, before entering on such details as depend on climate, or the kind of permanent-way and similar engineering considerations, it is necessary to decide the earlier question as to what type of vehicle will best suit the habits of the people, and in regard to this, social and even political considerations will be found to have weight. On many of the Continental railways, military exigencies are allowed to prevail, both in regard to the course of the railways and the dimensions of the rolling-stock, and the convenience of ordinary travellers is studied only after these conditions have been satisfied.

Passenger carriages.

Suitable types.

In some countries, such as in Cape Colony, the majority of passengers travel first class, the cheaper carriages being little used except by the natives. In India, on the other hand, nearly all the passengers travel at the cheapest rate. In the United States, democratic institutions abolished all distinctions of classes, but of late years the subsequent extensive use of sleeping, drawing-room, and hotel cars at extra fares, has added a specially luxurious class. Even for those who cannot afford to pay the extra charges it is necessary, because of the long distances, to provide sleeping accommodation, and emigrant trains are furnished with berths as on board ship.

Classes of passengers.

Sleeping cars.

In Great Britain, for a long time after railways were established, no attempt at comfort was made for any but first-class passengers, and both in regard to the times of departure and speed of trains, as well as to the construction of the carriages, actual discomfort and inconvenience were inflicted on all who travelled in any other than first-class carriages. This old and foolish policy has been completely reversed, third-class passengers being almost universally carried at ordinary fares in comfortable carriages, and by all trains, however fast. This has resulted in a large increase in the number of the most remunerative passengers, the third class, while the decrease in the second class will probably lead to the abolition of that class, leaving only the first and third, an arrangement which considerably simplifies the working of the traffic, and reduces the dead weight of trains. It may be stated as an axiom that the fewer the kinds of carriages, the better for the cheap and profitable working of the railway; and while some variety of kind or class of carriage is necessary to meet the reasonable wants of the public, the variety caused by individual predilections, or exceptional demands, are expensive and unnecessary. Where very long journeys have to be undertaken, or where there are different races of people—as colonists and natives, or, as in India, where the caste customs of the natives have also to be considered—a great variety in the kinds or classes of carriages is often absolutely necessary.

Modern systems in Great Britain.

Cheap traffic encouraged.

Three classes of passenger carriages.

Carriages giving a longitudinal passage throughout the train are usual in America, and have been adopted with more or less modifications on numerous railways in Europe and elsewhere, but do not find general favour in Great Britain, although they are followed in some of the British colonies. The freedom of movement for the passengers, the facility afforded for lavatories, stoves, refreshments, and other conveniences, and the passage from one carriage to another while travelling, alleviate the tedium of long journeys. Such carriages also allow the issue or collection of tickets during the journey, and in sparsely-peopled countries, or where it is desirable to save the cost of buildings, much of the work usually done at roadside stations may be performed by the conductor, who perambulates the carriages during the journey. On the other hand, the want of privacy—often of importance to ladies, children, and invalids—has retarded their popularity in Europe. There is the disadvantage also that the construction of the carriages allows doorways only at the extreme ends, and if there be many passengers, or if there be frequent stoppages or

American type of cars.

Advantages. *See also page 61.*

Convenience of side doors.

much changing of trains, the time occupied in the entrance and exit of passengers is inconveniently long, an objection, especially in city or suburban traffic. The trains specially built for the passengers from Chicago to the Columbia Exhibition were for the latter reason constructed of the English type. Moreover, in case of accident to the train, passengers have not the same opportunities for escape as in an English carriage, and owing to the absence of partitions, the cars are more liable to be "telescoped" in collisions. But on the other hand, the absence of side-doors allows a greater width in the body of the car, and as also the over-bridges and tunnels (less numerous in proportion to the mileage than in Great Britain) have a larger contour, the loading gauge is larger on American railways than in Europe for the same gauge of railway. The American style of car is best suited for long-distance journeys occupying more than five hours, while the British fashion of separate compartments is, under most circumstances, greatly superior for short journeys or suburban traffic. Cars on the American plan, with a longitudinal central passage, doors at the ends only, outside platforms, and carried on two bogies of four or six wheels each, are considerably heavier, longer, and more costly for the number of passengers carried than the usual style of European railway carriage. The latter is divided into compartments with side-doors, and up till about 1890 was almost always carried on four or six wheels connected directly to the main frame; but carriages with the English system of separate compartments have since been made on the leading railways with swivelling bogie-trucks for easy motion in passing round curves. An ordinary American passenger-car seats about 52 passengers, is about 47 ft. long over the body, and 53 ft. over all, and weighs from 19 to 24 tons empty. An ordinary English main-line third-class seats 50 passengers, measures about 31 ft. over the body, and about 34 ft. 6 in. over all, and weighs from 10 to 12 tons empty. An American parlour or drawing-room car with revolving seats, and carried on two six-wheeled bogies, weighs from 27 to 32 tons, and contains seats for from 24 to 37 passengers. The length over all varies from 60 to 70 ft. Sleeping-cars capable of accommodating from 20 to 27 passengers are of very similar size and weight. An English first-class main-line carriage seats 24 passengers, measures about 34 ft. over all, and weighs from 11 to 14 tons. An American train, accommodating 300 passengers at the lower, and 100 passengers at the higher rate of fare, with provision for their luggage, weighs about 240 tons empty, and measures

As at Chicago Exhibition.

Convenience of end doors.

Spacious cars.

Best for long journeys.

English carriage on bogie-trucks.

Size and weight of English and American cars.

Weight of trains.

620 ft. in length. An English train of corresponding capacity weighs about 150 tons if rigid wheel-base stock is used, and about 170 tons with bogie stock. In either case the English train would, without engine, be about 440 ft. long. The wheels, axles, axle-boxes, springs, and under-frames in the English stock would be larger and stronger than in the American, thus giving greater safety and durability, while the greater convenience of lavatories and central passage in the American stock would be offset by the more comfortable upholstery of the English stock, and the more convenient stowage for parcels and hand-bags. The American train would be carried on 50 axles, and the English train of bogie carriages on 36 axles, making an important difference in the number of parts in the running-gear.

Number of wheels and axles.

In regard to the running of the carriages on the road, the arrangement of the wheels usual with the American cars can, as already said, be adopted with carriages divided into compartments in the European manner. Such bogie carriages are not only extensively used on some of the principal British railways, but have been largely exported to the colonies. They combine the good points of English and American stock, the dead weight and cost being only slightly greater than for carriages with rigid wheel base, while the smoothness of running over rough roads, and the ease with which sharp curves are traversed, render them well adapted for lines in new countries.

British and American systems combined.

Climate.

The exigencies of climate have an important bearing on the designs of carriages. In Great Britain the extremes of heat and cold last but a short time, and are considered sufficiently met by the provisions for excluding the wind and rain. But this is not sufficient elsewhere, and in Russia, Canada, and Scandinavia, extreme cold demands special kinds of doors and windows, stoves or more elaborate heating apparatus being essential in every class of carriage. In India, South America, and other tropical countries the extreme heat renders necessary sunshades, louvre blinds, and other means of ventilation; and double roofs are provided not only for all classes of passenger carriages, but for horse-boxes also. In such hot climates special materials of construction have to be adopted; certain kinds of wood are found unsuitable; indiarubber, if used, has to be of special kinds; and the seats and upholstery have also to be different to those in temperate or cold climates. Railways have been so widely extended that a varied experience has accumulated in all these matters which should be utilised in new cases as they arise, and in England the

Extreme cold.

Extreme heat.

Special materials necessary.

Accumulated experience.

makers of railway carriages supply rolling-stock to all parts of the world.

Gauge of railway. *See page 67.* The gauge of the railway is the primary or ruling circumstance which has to be considered in the dimensions of rolling-stock. The narrower the gauge the lower must be the centre of gravity of the carriages, and this limits greatly the scope of the designer; and **Determines many points.** though by proper arrangement it is found possible to make passenger carriages for the narrowest railways, yet the speed at which the carriages can run safely is less for narrow than for broad gauges. On the other hand, there is the advantage that carriages running on a narrow gauge can pass round sharper curves.

Number of passengers. The amount of passenger rolling-stock necessary for a new line or even for a given traffic, cannot be decided with certainty, but the following facts, which apply pretty generally, may aid a decision:—

1. In Great Britain the average number of passengers in a train at one time is about 70.

2. One-third of the seats in the average train are filled.

3. The weight of passengers' luggage on through trains nearly equals the weight of passengers.

There are numerous exceptions to these averages which, for instance, do not apply to suburban or city traffic, and trains conveying 600 passengers are often run in England, while an average train load of over 200 passengers obtains on several Indian railways.

English carriages larger than formerly. The passenger carriages made on the earlier railways were inconveniently low and narrow as compared with those made later, the dimensions of the old post-chaises having been apparently the standard first adopted. The experience gained in railway running has shown that the longer, wider and higher carriages, which are necessary to the comfort and convenience of passengers, can run safely without increasing the width of gauge. Thus, on the standard-gauge lines, carriages instead of being made as formerly 5 ft. 6 in. high from the floor to the centre of the roof, are now made of heights ranging from 6 ft. 8 in. to 8 ft. The height and width of bridges have of course to be considered.

Materials. The bodies of both carriages and wagons of all kinds are almost always built of carefully-selected timber, iron or steel being only used to bind the mass together and for purposes where its use is unavoidable. While timber, owing to its low cost, is still exclusively used for the underframes of American cars, iron and steel underframes are very generally used on the Continent, and have been adopted by some

English railways. The carriages built in England for use in India and other tropical climates are built almost exclusively with steel underframes, while mahogany is largely used for the bodies. Underframes of iron or steel, if skilfully designed, are stronger, more durable than if made of wood, are about the same weight, and are less damaged in shunting or moderate collisions. Wooden underframes are also liable to be attacked by white ants and rot, and the fastenings are apt to work loose. This latter defect is avoided in properly made steel underframes riveted by hydraulic power. On the Continent iron or steel is also used for the panelling of the body of passenger carriages. Such panels are heavy and render the carriages noisy, and hot in summer and cold in winter. These faults may, however, be prevented by good upholstery and by the interposition of india-rubber buffer cushions between the underframe and the body, a device which is universal on British railways and very general on the Continent. In American cars the underframe and body form part of the same structure, but the consequent noise and vibration are lessened by a double floor, the space between being in some cases filled up with shavings, which often catch fire after a collision.

Steel underframes.

Advantages.

Good upholstery.

Vibration avoided.

Wheels.

The wheels of railway carriages and wagons are made in various ways. On the earlier tram-roads and railways the wheels were of cast iron, but these proved unsuitable, and unsafe for quick running or heavy traffic, and have consequently in Great Britain been superseded on all railways by wheels made wholly or partly of wrought iron or steel, though chilled wheels are used under contractors' tip wagons and on the small wagons or corves used in mines. Wagon wheels were formerly made with cast-iron centres and wrought-iron spokes, but the spokes, and sometimes also the centres, are now made of wrought iron. By the "cold spoke" method of manufacture the body of the wheel becomes a solid structure of wrought iron united without a weld by hydraulic pressure. Such wheels are practically indestructible, are somewhat lighter than the old style with cast-iron centres, but cost rather more. But whatever the arrangement of these compound wheels, the tires are always made in a separate piece of steel rolled in a ring, the wheel being turned, and the tire bored with extreme accuracy and shrunk on to ensure a tight fit. There are various ways of fastening the tires, but for safety in quick running it is sought to avoid weakening the tire by holes made in it for bolts or rivets. As accidents have frequently been caused by tires breaking and leaving

Cast iron and wrought iron.

Steel tires.

See page 559.

the wheel, it is endeavoured, in the manufacture of wheels for passenger carriages, so to attach the tire as to prevent it coming off even if broken into several pieces. This is ensured in the Mansell wheel, which, though more expensive than other kinds, is, in the almost universal opinion of English engineers, the best for passenger carriages. In it the tire is ingeniously held by side plates or rings, which serve also to hold together the body of the wheel, which is composed of solid teak-wood segments tightly wedged together between the nave and the periphery, to the former of which they are bolted. Wheels of this sort run more freely than those in which the spokes are open to the wind; they are also less noisy and stir up less dust. But the Mansell and other similar modes of fastening can be applied also to spoke wheels as well as to those with wooden centres, some engineers considering the latter unsuitable for brake carriages, as the centre has a tendency to turn when the brake is applied to the tire. Wooden centres are generally considered unnecessary for wagons, and are also unsuitable for climates where the temperature or amount of moisture varies considerably, as in India, Canada, and many of the colonies. In the United States solid cast-iron wheels are used universally under freight cars. Made of high-quality cast-iron, the risk of brittleness is reduced by a softening or partial annealing, and the tread is rendered harder than steel by being cast in an iron mould or chill. These wheels are very liable to sudden failure, and despite every care in manufacture their life is very uncertain. They are therefore fast being superseded by steel tires under the best class of American passenger cars, and for the engine and tender bogies of locomotives. Cast-iron chilled wheels are much cheaper in first cost than the safer and far more durable steel-tired wheels made in England, and form one of the numerous points of difference which have to be considered in comparing the prices and quality of English and American rolling-stock. Chilled wheels are not perfectly round, are not exact to size, and when once worn or badly skidded by the brake must be thrown away. Their average life varies greatly owing to their uncertain quality; but it is much less than that of an English wagon wheel, the tire of which can be renewed by re-turning it in a lathe; and when the tire is worn out the old skeleton of the wheel is fit for a new tire.

Fastening of tires.

Mansell wheels.

Wooden centres.

American chilled wheels.
See also page 702.

Will be superseded by steel.

Durability.

The wheels used under passenger carriages in Great Britain vary from 42 in. to 48 in. diameter on the tread, or portion which bears on the top of the rail. Wagon wheels are generally 36 in. diameter.

Diameter of wheels.

Sold in pairs. **Prices.**

The wheels of narrow-gauge rolling-stock range generally from 22 in. to 33 in. diameter for both goods and passenger vehicles, as both run at the same speed in the same mixed trains. Wheels and axles are generally sold by the " pair," namely, one axle and two wheels. The price of wagon wheels with steel tires and axles, Mansell or similar tire fastenings, and wrought-iron naves and spokes, united by the cold-spoke process, ranges from £9 to £12 per pair for standard-gauge wheels, and from £6 to £8 per pair for narrow-gauge wheels, the dimensions being given above.

Axle-boxes. **Oil or grease lubrication.**

Axle-boxes are always fitted with brass bearings and are also usually sold per set of four. They range in price from £4 per set of four for those suitable for wagons, up to £7 per set for the more elaborate oil-boxes for passenger carriages. The above prices are for standard (4 ft. 8½ in.) gauge vehicles. Lubrication by oil is superseding that by grease, the axle-box being provided with a well-fitting dust-shield of felt or leather or vulcanite, combined with suitable spring lubricating pads, supplying oil to the underside of the journal. If the axle-boxes are properly made, and if good oil be used, the friction during running is much less than is the case with grease. The consumption of oil almost entirely depends upon the dust-shields and axle-box covers being oil-tight.

Light and ventilation. **Electricity.** *See page 269.*

Other modern improvements in carriages have been in the direction of better light and ventilation. High omnibus roofs have been introduced on several English lines, and more window area provided. Different systems of using oil-gas of high illuminating power in a compressed portable form have been tried, and have superseded the simple but inefficient oil lamps, which are dirty and costly. Electric lighting by portable accumulators, or by dynamo-generators worked by the axles of the train, are also used, and when improved and reduced in cost are likely to be widely adopted.

There are four distinct systems of heating railway carriages :—

Heating of carriages.

1. Foot-warmers, generally of copper, containing hot water or acetate of soda. This plan, though simple, only suffices for such mild climates as England or France, and involves considerable labour at stations.

Stoves.

2. Cast-iron stoves. These are only suitable for the American style of car ; the heat is not well distributed ; the stoves are dangerous to life in collisions, and are forbidden by law in some parts of the United States.

Hot water.

3. Furnaces protected by a wrought-iron casing and heating hot-

water pipes are practically safe. The furnace can be applied beneath a compartment carriage.

By steam from engine.

4. Heating by live or exhaust steam from the engine is safe and effective, but the engines and carriages must all be fitted with the proper pipes and couplings. This method had, by 1898, been adopted on some of the principal British lines.

Increased weight of carriages.

The enlargement of the carriages and the various other alterations above referred to, have considerably increased the weight, so that, even allowing for the greater number of passengers which large modern carriages can convey, the weight of the carriage bears a larger proportion to that of the passengers carried than formerly. Against the conveniences obtained have therefore to be set the enhanced cost of the carriages, the greater expense of haulage, and the wear and tear upon the road; the latter being to some extent counterbalanced by the improved elasticity of the springs. The resistance at a high speed is augmented more by the greater size and wind surface than by the increased weight. On inclines, the weight is the important factor.

Wind resistance.

Purchase of carriages.

Carriages for use in the country of manufacture are almost invariably purchased complete; that is to say, although various trades are concerned, and carriage-builders do not make all the parts, it is considered inexpedient to divide the purchase; and the responsibility for the whole is put upon the builder. For exportation, also, complete carriages are generally purchased, for now that the principal carriage-builders manufacture wheels and axles, the custom of making separate contracts for these parts is less frequent than formerly. But for the maintenance of rolling-stock it is often found advantageous to make separate contracts for the various parts, a usual division being (1) wheels and axles; (2) axle-boxes fitted complete; (3) buffer-guides and other castings; (4) bearing and other steel springs; (5) wrought-iron forgings, such as buffers, draw-hooks, knees, bolts, straps and brake-work; (6) india-rubber springs; (7) upholstery trimmings; (8) lamps; (9) door-handles, and other mountings or fittings. In cases such as these, the body of the carriage may be either made in the importing country from indigenous timber or the wood-work may be also sent out in pieces. If all the wood-work is imported, the whole carriage should be fitted up complete in the country of manufacture, and then taken to pieces and packed. Carriages can be specially designed for this: the floor, roof and sides all forming flat pieces of nearly similar size, fitting into one packing case; the ends and partitions going into another. While a systematic plan of

Contracts for separate parts.

Packing for shipment.
See page 445.

this sort is necessary to ensure accuracy and completeness, the woodwork can, if necessary, be made in the importing country, and the little deficiencies and unavoidable inexactitude of a mixed structure be made good there. The smith's work is also sometimes made in countries which have to import most of their equipment, one complete set of forgings being sent out as a pattern. Special precautions are of course necessary to ensure the proper fitting together of parts bought from so many different makers, and it is usual to supply to all concerned samples of those parts to which connection will eventually have to be made. On most railways, standard patterns are kept of all the essential parts, and certain main dimensions are prescribed to which absolute uniformity is demanded.

Wood-work omitted.

Smith's work.

Precautions to ensure fitting.

Approximate prices.

Excluding exceptionally high or low prices which have occasionally prevailed, the following are approximately the prices of some leading types of carriages for standard-gauge railways during the ten years ending 1898.

Carriages of usual English type.

Third-class carriages about 30 ft. long in five compartments, with seats for 50 passengers, mounted on six Mansell wheels with steel tires, cost from £300 to £400 and weigh about 11 tons. First-class carriages of the same total length, with similar wheels and underframes, and differing only in having fewer compartments and more elaborate fittings, cost from £400 to £500. Composite carriages of similar length on three pairs of wheels, and divided into different classes and a luggage compartment, cost from £350 to £450. The more modern carriages, 40 ft. to 45 ft. long, on two four-wheel bogie-trucks, cost from £500 to £600 for third-class, and £700 to £800, for those composed of first and second-class, while special carriages with elaborate or peculiar fittings may cost from £1000 to £1500. The above prices are exclusive of the cost of packing for shipment, which, including the labour of subdivision, ranges from 4 to 6 per cent., or even up to 10 per cent. if cases be lined with zinc. Carriages on two six-wheeled bogies are longer, heavier and more costly in proportion to the number of passengers carried, but ride more smoothly. Dining and sleeping-cars are generally made with six-wheel bogies to ensure smooth riding. A dining-car, 55 ft. to 60 ft. long, costs about £2500, and a sleeping-car rather less. The price of such cars, and of directors' and private cars, differs greatly with the amount and style of decoration.

Carriages on bogie-trucks.

Dining and sleeping-cars.

Narrow-gauge carriages.

Narrow-gauge carriages cost less than those for standard-gauge railways, but rather more if estimated in proportion to their weight and the number of passengers carried. Thus, to take a few types of carriages for mètre-gauge (which would apply generally to 3 ft. and 3 ft. 6 in. gauges also), a third-class carriage, 20 ft. long and 7 ft. wide, with 4 compartments, each carrying 8 passengers, and fitted with brakes and centre buffers, would cost from £175 to £230, and weigh about 5 tons; a first-class carriage about 20 ft. long in 3 compartments, £250 to £300. Smaller carriages for carrying 12 first-class or 18 third-class passengers would cost about one-fourth less than the above prices. Narrow-gauge bogie-carriages, about 40 ft. long and seating 56 third-class passengers, cost from £400 to £500, and similar first-class carriages, seating 36 passengers, about £600 to £700.

Choice or design how determined.

A proper choice or design of a railway carriage can only be made on the basis of full information—in the first place concerning the number and class of persons to be carried, and secondly in regard to the circumstances of the railway, to which all the rolling-stock must conform. Very great inconvenience and loss have been incurred in countries importing rolling-stock, because owing to want of these necessary particulars the vehicles proved insufficient or unsuitable.

See page 731.

Continuous brakes.

See also page 700.

The weight and cost of railway carriages have been increased by the introduction of continuous brakes; and though these brakes were at first confined to railways having busy traffic, their usefulness has led to their general adoption, especially on lines having numerous or severe inclines. The different kinds of air-pressure brakes do not differ much in regard to weight or cost. With actuating apparatus on each carriage, and with brake blocks on each side of four wheels, the extra weight on a carriage ranges from 10 to 13 cwt., and the total cost from £30 to £35 per carriage. When applied to goods wagons the cost is less. The various systems of chain and other mechanical continuous brakes are less costly and slightly less weighty, but seldom so efficient, and are rapidly going out of use.

Goods wagons.

In the selection or design of *Railway Wagons* for the conveyance of *Merchandise*, it is even more important than in the case of passenger carriages that the existing rolling-stock on the same or on contiguous railways, or on those with which future connection is likely, should be considered, and uniformity on essential points be observed. But independently of this uniformity, which is necessary to through transit, different railway companies have their own rules

Standards of strength.
See page 733.
Essential to through traffic.

in regard to strength and fitness, and will not allow wagons which do not reach their standard to run upon their lines. Such uniformity and conformity to rules allow of through transit of goods over several railways without change of vehicle, greatly promote traffic, and save time and expense. In the transport of merchandise, the circumstances to be considered are those already enumerated as common to all rolling-stock, but the proportions and the general conditions are very different to those of passenger carriages.

Carrying capacity.
Tare weight.
Non-paying load
Railway accounts analysed.
See page 69.

One of the first points to be considered in the designing of goods wagons is their shape and size for the goods to be carried, and how best to carry the maximum quantity of what may be called paying load, with the minimum of non-paying load or tare of the truck itself. As the usual rates of carriage for minerals and merchandise range from ½*d.* to 2*d.* per ton per mile as compared with rates for passengers and their luggage, equivalent to from 6*d.* to 30*d.* per ton, it is evident that the proportion which the non-paying load bears to the paying load is of immensely greater importance for goods than passenger traffic, even taking into account the greater speed and therefore greater haulage cost per ton of the latter. In countries where there is competition, or where low tariffs are prescribed by law, so closely does the cost touch upon the sums earned, that it is probable that much of the cheapest traffic—generally that of minerals—involves actual loss if the hauling and returning of empties or partially filled wagons be taken into account; and on all railways, and even where rates of carriage are not cheapened by competition, very careful analysis of the varied expenses of a railway is necessary to ascertain the actual facts and to apportion to each kind of traffic the profit or loss accruing from it.

Capacity of British wagons.

It is difficult to define the capacity of goods wagons. As used for general merchandise on British railways, the nominal or maximum capacity is 8 or 10 tons, and the actual average load carried is about 2½ tons. The actual capacity of coal wagons varies in different districts from 7 to 10 tons, and as they almost invariably run back to the collieries empty the average load is from 4 to 5 tons. The nominal or maximum capacity of American bogie-cars varies from 13 to 27 tons, the oldest being of the former and some of the newest of the latter capacity. The most usual size is that for carrying 18 tons, and the actual average load varies from 6 to 9 tons. The usual maximum train on British railways is limited to 45 or 50 wagons if laden with merchandise, or 30 to 35 wagons if laden with

Weight of goods train.

Speed of goods trains.

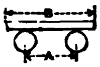
coal, cattle or iron ore, &c. Such a train weighs, with engine, tender and brake vans, from 350 to 400 tons, and can be readily shunted out of the way of passenger trains, or hauled up a gradient of 1 in 100 by an ordinary British goods engine weighing about 40 tons. Heavier or longer trains are exceptional, but are used where the gradients are favourable and no fast passenger trains are run on the same line of rails. Where high speed is desirable for perishable merchandise, the number of wagons is reduced to 25 to 30, but a through goods train of 45 wagons can be generally run at a speed of 20 to 25 miles per hour including stoppages, the speed on a level being over 30 miles per hour.

American goods trains.

The actual average load carried in a British goods train cannot be exactly determined, but careful observations show that it is probably about 80 tons for goods trains, and about 100 tons for mineral trains. The average train load in the United States is slightly below 100 tons. The difference is not as great as is generally imagined, and is chiefly due to the lower speed, the lighter construction of the American cars, the more level nature of the country allowing better gradients, and the use of heavier and more powerful goods engines. These factors, in increasing the average train load, are neutralised to a certain extent by the rough permanent way, the severity of the winters, and the rough and cheap construction of the cars, all of which factors increase the train resistance.

Width of wagons.

The width of wagon is of course limited by the gauge of the railway and by the loading-gauge which bridges, tunnels and other existing structures render necessary; and on British standard-gauge railways it hardly ever exceeds 7 ft. 6 in. Wagons have to be narrower than passenger carriages, to allow for doors left open, loose tarpaulins, and other possible projections. In regard to length, while there is more room for variance in the design, turn-tables, weigh-bridges and hydraulic lifts, when once established, limit the dimensions; while safety in running limits the length of wheel-base, and, with certain qualifications, the length of carriage also.



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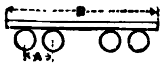
Length of wheel-base.

On British railways 8 ft. 6 in. is a usual length for the wheel-base A, and it seldom exceeds 9 ft. A customary proportion is 65 per cent. of the length of the body of the wagon, which is seldom allowed to overhang more than 3 ft. at each end, the total length, B, ranging from 14 ft. to 16 ft. Wagons for special purposes are occasionally made longer. Wagons of these moderate dimensions are convenient for marshalling and shunting, require turn-tables of



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small diameter, and can be made strongly with moderate weight. In the United States, while the advantages of a short wheel-base are, because of the less perfect roads, even more necessary than in England, it is allied with much longer wagons, for by the use of bogie-trucks the rigid wheel-base, A, is only about 5 ft., while a total length, B, of from 28 ft. to 34 ft. is obtained. The bogie wheel-base must never be less than the gauge of the railway.

Choice of long or short cars.

Long distance journeys.

Points to be considered.

Wagons for short journeys.

Short wagons for quick speeds.

In the choice between these long wagons and those of British pattern, somewhat the same considerations prevail as determine the choice in passenger carriages, i.e. the larger vehicles are generally preferable for long journeys. For instance, if large quantities of produce or merchandise have to be sent several hundreds of miles from or to a port, large wagons can be filled, involving less dead weight, fewer couplings, and making shorter trains than would smaller wagons of the same total carrying capacity. The longer the average journey, the less is the proportion of shunting and marshalling operations, and the saving in haulage-cost which the long wagons allows is less neutralised. Thus, while in America a wagon may run 1000 miles and remain undisturbed in its place in the train, an English wagon may in the same number of miles make twenty trips, and require to be moved by a horse or by a hydraulic capstan, to descend and ascend a lift, and to be put on a turn-table once or twice on every trip. It will be seen, therefore, that large and small wagons have each their appropriate duty, and that neither type has an absolute superiority. Even if a change to the American system were desirable, the fact that existing turn-tables and lifts are of a certain limited size would forbid it on railways of British construction. Even in America, where long wagons are the rule, coal, which is to be hauled a less average distance than is usual with produce, is generally carried in four-wheel wagons smaller than those in England for the same purpose. Speed has also to be considered. Where there is a busy traffic, the goods trains have to be continually shunted to allow quick trains to pass, and even with this relief have to be run at a speed which is expensive, in order to keep the line clear for passenger trains. Long or heavy wagons are not suitable for such treatment; but by the construction of duplicate lines for minerals and merchandise, slower and heavier trains may be adopted, thus reducing the objections to large wagons.

Tarpaulins.

In Great Britain it is usual to protect goods conveyed in open wagons by large tarpaulins thrown over the goods and firmly laced down to the sides and ends of the wagons. This method saves weight, but the tarpaulins are apt to get lost, torn, and worn; and unless carefully tied, become loose and allow the wet to enter. If the first cost of the tarpaulins and their rapid wear and decay be taken into account, as well as the damage sustained by goods from the insufficient fastening of the tarpaulins, the alternative of closed wagons will generally prove the most economical. Although on American railways cheapness is much considered, covered wagons are, for the above reasons, preferred to tarpaulins.

Are ineffective.

Within the limits prescribed by the foregoing considerations, there is still room for much diversity of design. If the goods to be carried were uniform in kind, and sufficient to fill the trucks, there would be little difficulty in arriving at a decision as to the best size. A permanent-way strong enough for locomotives has an ample margin for wagons, and the maximum weight is rather determined by the amount which a horse can, in the operations of marshalling and shunting, not only draw, but start.

Diversity of design.

Hydraulic capstans are largely used instead of horses at important stations, and especially where the same hydraulic power is or can be used for cranes or hoists. At small stations a peculiar form of pinch bar or lever is often used by which one man can easily move the heaviest wagons.

Hydraulic capstans.
See pages 610 *&* 803.

In the case of mineral traffic, the haulage of the empty return wagons has also to be considered, and the comparison between paying and non-paying load has to be calculated on the basis of one journey of the former to two of the latter. It is of course the aim of railway managers to avoid such unremunerative hauling; but, though it can sometimes be reduced, it can seldom be avoided altogether. A favourable opportunity is found where there is an exchange of minerals. Thus, in an iron-making country, where the coal and iron mines are not contiguous, coal may be taken to the ore and ore brought to the coal, the wagons being thus employed in both directions. In the iron districts of Northamptonshire and Lincolnshire blast furnaces have been established, and are supplied with coal from other counties, the coal wagons taking back ore to the blast furnaces in the coal districts. This is a rare case, and in England generally the coal traffic is too great to allow of return cargo for the wagons. And in most countries, even when there is a great interchange of traffic, the goods to be carried are of a very different character, and the proportion of tare weight to be hauled different accordingly. Some-

Empty wagons.

Unremunerative haulage.

Mineral wagons.

See page 353.

Gradients. *See pages* 63 *&* 693. times the difficulty is minimised by the direction of the gradients. Thus a railway for conveying minerals or metals from the interior of a country to the coast for shipment may be mostly downhill, and the lighter return loads may be appropriate to the return journey.

It is obviously impossible to lay down a rule for the proportion of tare weight to paying load where the nature of the merchandise **Load limited by bulk as well as weight.** varies, and where, as in the stowage of a ship, bulk as well as weight limits the amount to be carried. And though, where there is a large staple trade of one particular kind, the wagons may be designed to suit it, they can seldom be the best for both journeys, and some compromise must be adopted. But with all these drawbacks, it is a reciprocal commerce which cheapens transport, and new trades, opening out new sources of revenue for railways, are generally developed *See page* 467. where there is unrestricted interchange of commodities. Even where there is a large or staple traffic in light goods, it is dangerous to make wagons of strength and weight proportionate only to such load, for **Risk of heavy goods in light wagons.** there is always a risk that goods of other and heavier kinds may occasionally be placed in them on a return journey. And however light the merchandise, the wagons may have to form part of a miscellaneous train, and must be strong enough to transmit the haulage force and to bear the shocks of running and shunting.

Variety of wagons. On all railways there must be various kinds of wagons for the different merchandise, but the fewer the types with which the traffic can be carried on, the more cheaply is the line worked; the inconveniences and expenses which great diversity causes being proportionately greater on a small railway than on a large one. The question is one for which no general rules can be established, but must be settled according to the circumstances of each case. On British **Diversity a cause of expense.** railways the diversity of wagons is very great, but the evil is minimised where there is enough traffic for each kind of wagon. A less variety is necessary in Ireland, where the traffic is chiefly in manufactured goods, raw materials liable to damage by wet, and **One type serves for various goods.** cattle. One type of wagon can be used for various kinds of loads, because high cattle wagons can (after the compulsory cleaning they undergo) be utilised for casks, coke, sleepers, drain-pipes, dressed timber and other undamageable goods. Bale or sack goods, which must be effectually protected from damage or pilfering, and are valuable enough to bear a higher rate of carriage than cheaper goods, **High freight rates allow for tare.** can be conveyed in the covered wagons, the extra tare weight of which still allows a remunerative return for the haulage. On the other hand, when stone, pig-iron, or slates have to be carried, for which low-sided wagons are sufficient, the tare weight should be brought down to the lowest point which the safe working of the railway will permit. In short, while the *Size* of wagons depends principally on the length of the journey, so does the *Form* depend on the nature of the goods to be conveyed.

Size and form how determined.

In the earlier days of railways it was deemed unnecessary to furnish wagons with springs, but the effect on the permanent-way and on the frames of heavy wagons without such alleviation of the shocks—especially during the quick running necessary to allow numerous trains—soon rendered bearing-springs necessary. And on most railways spring buffers and spring draw-bars are also adopted. The improvements in goods wagons since the earlier days of railways have, however, been slight compared with those in engines and carriages during the same period. Improvements have been mainly in the direction of greater strength and durability, especially in those parts which have proved liable to sudden breakdown; while in the designing of details and in the material employed, facility for repairs is more considered than formerly.

Springs necessary for wagons.

Improvements in wagons.

Railway wagons are subjected to such severe shocks that the best and strongest materials should alone be used in their construction, the durability of the wagons and the cost of repairs depending also on the care with which the timber has been selected and seasoned. English oak, North American white oak, and pitch-pine are the woods most used in Great Britain for the framing of wagons, but the sheeting, flooring, and roofs are usually made of Baltic redwood. Formerly American spruce was used for cheap wagons, but this has been abandoned. For tropical countries, teak is mainly used. The substitution of iron and steel for wood as a material for railway wagons has often been advocated, even when for passenger carriages it is considered inappropriate, and it has been tried in various ways. If the stresses to which the various parts of a wagon are subjected could be clearly defined, the selection of material suited to each might perhaps be made with advantage. But the shocks and strains are so varied and peculiar that no such accurate apportionment can be arrived at; iron or steel cannot, in the opinion of most English engineers, be applied with advantage for the bodies; but iron and steel are gradually superseding timber for the underframes, wood planking stiffened and supported by iron knees and braces being still considered best for

Materials.

Oak and pitch-pine.

Teak for hot climates.

Strains on wagons cannot be defined.

Underframes, wood, iron, or steel.
See page 786.

all above the floor-level. The sides of bogie-trucks can be advantageously made of steel formed of one piece by hydraulic pressure, but on British railways the established dimensions of turn-tables and station lifts, as well as the necessity of shunting already referred to, forbid a change to the long American wagons. Wagons solely built of iron or steel are, on British and American railways, seldom made, except for peculiar purposes, such as the conveyance of hot refuse from blast furnaces, or other cases where the contact of the materials carried is damaging to wood. But for use in India and the tropics, where wood is liable to decay or to be attacked by ants, wagons are made entirely of steel. They are made cheaply in large quantities by special machinery.

Wheels and axles. The quality of wagon wheels and axles is of the greatest importance, for not only the term of endurance and cost of maintenance depend upon it, but the safety of an entire train is endangered if the defective wagon or wheel form part of it. On British railways, and on most of the colonial lines, the axles are generally made of steel, **Tires.** and are larger and better proportioned than formerly; the tires also are of steel, and are held to the wheels by various forms of fastening which avoid objectionable rivets through the tread of the tire. **Draw-bars and couplings.** The couplings, draw-bars, and hooks are subjected to such heavy shocks that they are always made of iron much superior to that used in other parts of the wagon, so that they may afford the necessary strength without inordinate weight.

The principal railway companies when buying rolling-stock from manufacturers generally present to them very elaborate specifications **Standard specifications prescribed.** of what is required, and though standards of size, kind, and quality have been established, improvements are from time to time introduced. But on many of the smaller railways, and especially those distant from the place of manufacture, the wagon-builders are often invited to offer their own designs. Rolling-stock can be suitably designed only on the basis of full information on the following points; and it is of the greatest importance that the particulars furnished by the purchaser shall be full and explicit, as the vague and indefinite information *See page* 458. often supplied, not only is interpreted differently by competing manufacturers and a proper comparison of prices hindered, but the stock when built may be unsuitable for its purpose. But if the railway is **New designs, how based.** an entirely new one, where interchange of traffic with existing lines has not to be provided for, the points of uniformity need not be so much regarded.

1. The *Gauge* of the railway, the section of the rail, and a description of the permanent-way.

Permanent-way.

2. The *kind of Goods* to be carried, with special regard to the following circumstances :—

The kind of goods.

(*a*) Whether the wagons are always to be used for the same class of goods, such as coal or iron.

(*b*) If for miscellaneous traffic, a description of the different *classes*, and some indication of the proportions of each.

Classified.

(*c*) Whether the goods will be of a kind liable to damage by *weather*.

(*d*) Whether the goods will be of a *fragile* nature, requiring special protection from damage in transit and during shunting.

(*e*) Whether valuable goods liable to *pilfering* are to be carried, and if so, what system, if any, is adopted or proposed, of bars, locks, or seals to prevent it.

(*f*) The maximum *weight and bulk* to be carried in each wagon.

3. Points of *uniformity* with existing vehicles on the railway or on neighbouring lines which are necessary or expedient, such as :—

Uniformity.

(*g*) Whether one central or two side *buffers* are used; if the former, its shape; and if the latter, the width between the centres of buffers.

(*h*) The *height of the floor* of the wagons from the rails.

Essential points.

(*j*) The *height of the buffers* and draw-hooks from the rails, and a pattern or drawing of the hook. The position, size, and kind of the sockets and holders for the side and tail lamps.

(*k*) A profile of the established *loading-gauge*.

Loading-gauge.

(*l*) The kind and dimensions of *wheels*, *axles*, and *axle-boxes*.

See page 711.

(*m*) The length of *wheel-base* usual or intended, and, if locking or detector bars are used at points, the length of the bar. If continuous brakes are used, the kind, with a sketch showing the exact position of the pipe-couplings.

4. The maximum *weight of train* of which the new rolling-stock is to form part, and the incline of the steepest or ruling gradient.

Weight and gradients.

5. Whether any sidings are situated on steep inclines, rendering *hand-brakes* on every wagon necessary.

6. The radius of the *curves* on the main line and in sidings.

Curves.

7. Whether oil or grease is used for *lubrication*.

Lubrication.

8. The nature of the *climate* in regard to the following points :—

(*n*) Extremes of *heat* which may render necessary special kinds of roofs or ventilation.

Heat.

Dust. (*o*) Prevalent *dust* or dirt which may require special protection for the axle-bearings.

Cold. (*p*) Severe winters requiring double lining and stoves in brake vans, or moderate cold which may render necessary stoves in brake vans for use in frosty nights, or during the crossing of mountains.

(*q*) Long journeys, requiring some sleeping accommodation in brake vans.

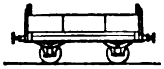
Rain. (*r*) Excessive rainfall.

Unsuitable materials. (*s*) Whether certain kinds of wood or other material have proved to be or are likely to be cheap, durable, or unsuitable.

Wagons made entire or in parts. 9. Whether the wagons are to be made *complete or only in part;* if the latter, which parts, and the kind, shape, and material of the parts to be added afterwards.

Advantages of good quality. The various improvements previously alluded to have increased the cost of rolling-stock, but the greater cost is justified by the easier running of the wagons, the less damage to the permanent-way, the greater security to the goods, and the less liability to failure, which is not only costly in itself but a cause of delay to other traffic.

Prices of British wagons. The most usual types of wagons on the railways of Great Britain and their prices may be tabulated as under, spring buffers being included in all cases:—



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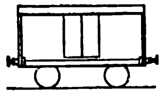

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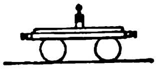


201.

	Approximate Prices.	Average weight in tons.
Low-sided (sides 12 in. high) for ironwork or iron ..	£55 to £70	4 to 4½
Medium (sides 36 in. high) the most usual in Great Britain (Fig. 199)	60 „ 75	4½ „ 5
High-sided (sides 48 in. high) for sack, bale, or bulky goods	65 „ 80	4½ „ 5
Covered for valuable goods (Fig. 200)	90 „ 100	6 „ 6½
Cattle wagons	95 „ 110	6½ „ 7
Salt wagons	85 „ 95	5 „ 6
Timber trucks (Fig. 201)	70 „ 80	4½ „ 6
Special trucks, as for thrashing machines or boilers	200 „ 300	12 „ 20
Goods brake-vans weighted with cast iron	120 „ 200	10 „ 12

Long wagons on bogie-trucks. Wagons carried on two 4-wheeled bogies are not used on British railways, but are extensively exported to India and many of the colonies. They possess many advantages, and are especially suitable for lines having rough permanent-way, or many sharp curves, or for narrow-gauge lines, where a 4-wheeled wagon is too small to accommodate bulky articles. They are also very useful where the line is being

See page 726.

Useful for railway making.

continually extended, as they can be used for the transport of rails, piles and bridgework, which cannot be conveniently loaded on small wagons. The greater size and dead-weight of bogie wagons render it especially important that they should always carry a load, and consequently they should be designed to suit a wide diversity of traffic. Thus, wagons conveying cattle from the interior of the country to the seaboard may have special end doors for loading rails or long timber on the return journey. Side or bottom flap doors may be provided for the discharge of ore, coal, or ballast.

Rolling-stock owned by railways.

In Great Britain, although the railway companies provide the rolling-stock for general merchandise they do not provide all the wagons for conveying minerals, such as ore, coal, lime, iron, and steel, a considerable proportion of these being owned by those whose minerals are carried. Owing to the diversity of ownership, vehicles of various designs, material, and workmanship running in the same trains have been the cause of numerous accidents. This, and the circumstance that the sorting and marshalling of empty wagons to give back each to its respective owner, involves much expense and delay, form an incentive to the railway companies to reduce the number of private wagons as much as possible. It has only been possible to partially accomplish this, as it involves a large capital expenditure; and it is seldom that railway companies avail themselves of the special financial societies that supply wagons on terms of hire or deferred payment. Meanwhile the railways most engaged in the traffic of heavy minerals have established rules and conditions of quality, and will not allow private wagons to run on their lines till, by careful inspection, conformity to these rules has been assured and recorded by an inscribed plate affixed to each wagon. The following leading particulars for a wagon to carry 10 tons of minerals on British railways will serve as an example current in the year 1898.

Sorting and marshalling.

Conditions of quality enforced for private wagons.

Prescribed dimensions.

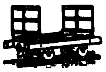
The maximum dimensions are 8 ft. width, 10 ft. height at ends, and 11 ft. 6 in. height in middle. The shackles and other draw-gear to be made of the best cable iron. The two axles to be of steel, not less than 6 ft. 6 in. in total length, not less than 5¼ in. diameter where fixed in the wheel, tapering to 4½ in. in the middle of the axle, and with journals 8 in. long and 3¾ in. diameter. The steel to be equal to a strain of 35 tons, and to endure a specified falling weight without fracture. The wheel tires to be of steel 5 in. wide and not less than 2 in. thick. Each wagon to have double brakes and cast-iron brake blocks, and buffers with laminated springs.

Axles and tires.

Narrow-gauge wagons.

For narrow-gauge railways, of which those of 3 ft., 3 ft. 3$\frac{3}{8}$ in. (one mètre), and 3 ft. 6 in. may be included together, the goods wagons, with central buffers and draw-gear, will generally weigh, cost, and carry from 20 to 40 per cent. less than those of similar type of the standard gauge.

Wagons for little railways between 2 ft. and 3 ft. gauge cost from £30 to £50; but on small-gauge portable railways, such as already described for plantations, mines, or farms, or for contractors' purposes, where earth-tipping wagons are needed of very small gauge, steel or iron wagons, weighing from 4 to 12 cwt., and without springs, can be purchased for from £7 to £15; and if the under-frame with wheels are alone purchased, for the addition afterwards of wooden bodies, these prices are diminished by about one-fourth. Narrow-gauge wagons should have central buffers.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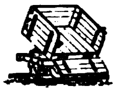
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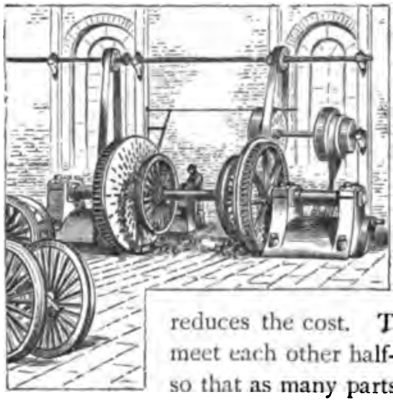
Contractors' wagons.

Contractors' wagons (standard-gauge) made of wood, with wrought-iron axles and cast-iron wheels, but without springs, holding from 80 to 100 cubic feet, and arranged for tipping end or sideways, cost from £15 to £25, and weigh from 30 cwt. to 50 cwt.

See also RAILWAYS.

CHAPTER XXV.

MACHINE TOOLS.



However much hand-made articles may, in some branches of the arts, be considered superior to the machine-made article, the reverse is the case in most engineering operations, for in almost all cases the aid which the machine process affords is found to improve the quality, while it reduces the cost. The engineer and the tool-maker meet each other half-way; the one framing his design so that as many parts as possible can be operated on by machinery; and the other, year by year, contriving new machines to supersede hand-labour. The artisan instead of having, as formerly, by his own sheer force to cut the metals on which he works, can now apply his skill to the higher function of setting out his work and superintending the machines which obey his will. The mere tending of the machines, and the adjustment of the cutting-tools can be performed by an ordinary workman, and the amount of finished work which a certain expenditure of time, money, and labour will produce is immensely increased, to the great advantage of the community.

Labour-saving machines.

Better work at less cost.

Early inventions.

The earlier inventors evolved the principles of the machine tools—such as the action of the planing-machine, slide-rests, screw-cutting gear—and for many years little improvement was effected on the forms adopted by the original makers. But ingenuity has since been directed to improvement in detail, and has been stimulated by the assistance rendered by the users, who, being themselves engineers or skilled workmen, have been able, more easily than could users of other machinery, to invent or suggest new contrivances. As applicable to engineers' tools generally, the following have been the most important of such improvements :—

Improvements in detail.

Better framing.

Friction reduced.

Electric motors. *See page* 611.

Accurate fitting.

The framework is better designed, and one piece or casting is, wherever possible, substituted for numerous parts bolted together; and a hollow section, which affords greater strength and stiffness, is preferred to the H, T, or X section formerly adopted. Steel and malleable cast iron are substituted for cast iron in parts exposed to torsion or percussive strains; spindles are made of steel instead of wrought iron, and ball bearings are used for thrust spindles; hardened steel bushes, which are long-enduring, or brass bushes which can be replaced, are used instead of unlined bearings, which were bushed only when worn; contrivances for taking up the wear are more usually supplied; and the overhead gear is of better form, and fitted with more powerful cone pulleys than formerly. Electric transmission instead of shafting, and electric " drivers," reduce the waste of power in giving motion to isolated machines, while greater facilities for attaching the work to the machine lessen considerably that expenditure of time and money in fixing, adjusting, and detaching the work, which often exceeds the expense in the actual operation of the machine. While in all engineers' work accurate fitting, true surfaces, and exact lines are desirable, these qualities are specially necessary in machine-tools which reproduce and multiply, in the work to which they are applied, the good or bad workmanship by which they themselves were constructed.

Engineers' tools classified—

According to mode of action;

Machine tools might be classed according to their mode of acting on metals, as—lathes, planers, and slotting tools, having a cutting action; shearing, cropping and punching tools, having a shearing action; emery-wheels and grinding-machines, as acting by abrasion; but it is deemed more convenient to classify them according to their purpose, as follows :—

According to purpose.

1. Machine tools for the makers of stationary, marine, and locomotive engines, and special tools for railway-carriage builders and other repetition work.

2. Machine tools for boiler-makers, ship-builders, bridge and girder makers, tank and gas-holder makers.

3. Smithy tools, including steam-hammers, power-hammers, and hydraulic forging-machines.

The special machines and appliances for iron and steel making, for

Tools other than for engineers omitted.

rifled ordnance and small-arms manufacture, for the cutting and manipulating of wood, fibres, fabrics and leather, all of which might be classed as tools, may be considered outside a strictly-defined category of engineers' tools, and are therefore not further alluded to here. Each of the divisions might again be subdivided, and generally according to the weight and strength of the machines, and a great variety of special tools included. It is, however, here only intended to give the leading types of machine tools, although incidentally variations or adaptations for particular purposes will be alluded to.

For the present purpose, however, the most convenient classification of machine tools may be made according to their kind, as follows :—

Machines classified according to kind.

Lathes, Drilling-machines, including horizontal drilling and boring-machines, Planing-machines, Slotting-machines, Shaping-machines, Milling-machines, Emery-machines, Screwing-machines, Cold saws, Punching and Shearing-machines, Riveting-machines, Plate-bending machines; Smithy tools, Steam-hammers, Power-hammers, Hydraulic Forging-machines, Hot saws.

Lathes.

Lathes classified.

Lathes stand first in order of importance among machine tools; and the various uses to which lathes are applied have greatly increased. It may indeed be asserted, in regard to steam-engines and general machinery, that the cost of workmanship depends mainly on the proportion of the circular or cylindrical work which can be performed by the lathe; and for this reason, engines and machines of all kinds—especially those which are made in large numbers alike—have their parts specially designed to this end. Lathes may be classified generally as ordinary *Slide-lathes*, where the cutting is principally external and parallel, or nearly so, to the axis, and in which the sliding of the rest may or may not be self-acting; *Screw-cutting lathes*, in which the slide-rest is not only self-acting but which can be made to advance automatically at any desired speed parallel to the revolving shaft; *Surfacing-lathes*, in which the slide-rest is self-acting, not only for sliding along but across the face-plate, these lathes being mostly used for turning across the axis and for internal turning or boring; *Hand-lathes*, for small and light operations, worked either by foot-treadle or by steam-power, in which the tool is held and moved by the workman instead of in a slide-rest; *Copying-lathes*, which reproduce, more or less automatically, a copy or pattern presented for imitation; *Multiple-lathes*, where two or more similar articles

See page 739.

See page 739.

See page 740.

See page 741.

See page 741.

See RAILWAY TOOLS, *page* 687.

placed parallel to each other are operated on simultaneously by their respective tools, all guided and moved by the same power. There are numerous other lathes made for special purposes, such as lathes for railway wheels, for oval turning, spherical turning, engine turning.

Slide-lathes.

Improvements in slide-lathes.

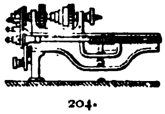
Turret tool-holders.

Facilitate repetition work.

The size or capacity of a *Slide-lathe* is, in England, stated according to that distance from the centre of the mandril-head to the face of the bed which determines the diameter of the article which can be admitted; and lathes are designated accordingly as 10-in. lathes (admitting an article 20 inches diameter on the face-plate), 12-in. lathes, and so on. In the United States, lathes are rated by the diameter, and the above two sizes would be designated as 20-in. and 24-in. lathes. It must be noted, however, that the radius of an article which is to revolve between the centres of a lathe is some inches less than the height of the centres, owing to the thickness of the travelling saddle, which for the sizes mentioned would be 3 in. or 4 in. respectively. Among the various modern improvements in slide-lathes, increased strength has been given to the mandril-head or fixed head-stock, and the fixing of the work in place has been expedited by well-contrived chucks. Self-acting or automatic feeds for moving the tool-holding slide-rest have been much improved by being made more direct-acting; and special tool-holders and shapes of tool-steel save time in adjusting and working. One of the most ingenious tool-holders is the revolving "turret" (sometimes known in England as the "capstan"), applied most frequently to 6-in., 8-in. and 10-in. lathes, and useful where the article under treatment has to be subjected to a succession of operations each needing a different tool. These tools, up to about six in number, are so fixed and adjusted in the turret that they can, by an instantaneous revolving movement of the latter, be brought to bear on the article in proper sequence. For repetition work these turret lathes allow great economy in time and money, as the constant resetting of the work or of a different tool, as in an ordinary lathe, is avoided.

Used as surfacing-lathes.

Slide-lathes can, of course, be used as surfacing-lathes, so far as the clearance space from the centre to the bed allows room for articles of a certain diameter, and this space may be increased by a gap in the bed at or near the head-stock. In some cases these *Gap-lathes*, as they are called, are made with a gap to open and shut with a screw (the bed moving back on a planed foundation-plate), so that articles of greater breadth than in a lathe without this contrivance



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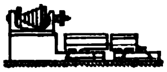
Gap-lathes.



205.
Sliding-gap lathes.

can be inserted. Such machines are known in England as sliding-gap or break lathes, and they are seldom used except in small factories where the number of machines is limited and the same lathe is applied to various purposes.

Accustomed sizes.

For general work in an engineering factory, there are certain accustomed sizes of lathes, those with centres of from 6 in. to 18 in. being the most common, though 4½-in. and 5-in. lathes are also usual in small trades. If there be no stipulation to the contrary, the beds of such lathes are made from about 5 feet long for a 5-in. lathe, to 20 ft. long for a 15-in. lathe; additional length involving extra cost. In small lathes, the size and therefore the power of the cone pulleys are much curtailed, and it is advisable to have ample strength in this respect. A 6-in. lathe costs from £40 to £60; an 8-in. lathe £70 to £100; a 10-in. lathe £90 to £130; a 12-in. lathe £120 to £160; a 15-in. lathe £180 to £250; and an 18-in. lathe about £300.

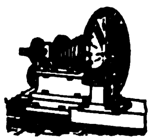
Special slide-lathes.

Slide-lathes are sometimes made for particular trades, and, being intended always for the same class of work, have more facilities for attaching the article to be treated and for operating upon it than is possible in those lathes which are intended for the miscellaneous work of an engineer's factory. Such, for instance, are the lathes for turning both journals of a railway-axle at the same time, the axle being held or chucked in the middle; the heavy lathes for turning the rolls used in the manufacture of bar and plate iron, or in the turning of crank-shafts or guns of the largest kind.

Screw-cutting lathes.

Screw-cutting lathes are an amplification of the ordinary slide-lathe by the addition to them of variable gear (trains of wheels) for moving the saddle or tool-holding slide-rest automatically at various speeds, in proportion to the revolutions of the spindle, so that a regular spiral or screw of any desired pitch can be made; a fully-equipped lathe of this sort having generally from 18 to 22 wheels to suit every variety of pitch of screw. These lathes are used when necessary as ordinary turning lathes, but if the screw is too frequently employed instead of the rack for the ordinary traversing of the saddle or rest, its accuracy and pitch are liable to become too worn for their real purpose of screw cutting. Screw-cutting gear adds about 10 per cent. to the cost of a slide-lathe.

Surfacing-lathes are those in which the article to be operated on is affixed only to the face-plate (which, having sliding jaws, forms a chuck) without being held by the loose head-stock at the further end



206.

Surfacing-lathes.

For large diameters.

Examples of face-lathes.

Two slide-rests.

of the machine; the bed of the lathe not rising much above the ground, and being used only for the slide-rest which holds the tools, and for attaching the article to be operated on. Surfacing-lathes are, as the name implies, principally used for face work or for boring, the tool having freer scope for such operations than when a central spindle held at both ends is employed. As the bed of a surfacing-lathe may be quite detached from the head-stock, there is no limit to the depth of the gap, and in extreme cases, such as the turning and boring of a fly-wheel, or the roller path of a turn-table or swing-bridge, a race excavated beneath the floor allows a wheel of large diameter to revolve. The size of a surfacing-lathe is generally expressed by the height of the head-stock from the bed (as in a slide-lathe) and the diameter of the face-plate. A face-lathe with 10-in. head-stock and face-plate 30 in. diameter costs from about £100; a 13-in. lathe with 36-in. face-plate, about £130; an 18-in. lathe with 60-in. face-plate, about £160. Much larger lathes are used in the manufacture of marine engines and other heavy work, and of these a 30-in. lathe costs about £250, and a 60-in. lathe about £500. Little face-lathes without a slide-rest, for turning small articles by hand, and often useful for turning wood and brass, cost from £30 to £50. In most surfacing-lathes there are two slide-rests, which may be used for making two cuts on the same surface; or one may be used for facing while the other is boring or turning the same article.

Choice of lathes.
See pages 472, 476 *&* 687.

For general work.

Speed-lathes.

In selecting lathes for an engineering factory, much depends upon whether the amount and variety of work are large enough to keep fully employed numerous lathes, each suited to its own particular work. In a small factory where the work is miscellaneous, such special machines would not repay their cost, and it is better to have lathes adapted for general purposes. For example, almost every kind of moderate-sized work may be done with only three lathes, which may conveniently be 6 in., 12 in. and 18 in., or 5 in., 8 in. and 12 in., according to the nature of the trade; and their general utility may be increased if each be made with screw-cutting gear, four-jawed surfacing plates, and with an opening gap to adapt it for a surfacing-lathe. Speed-lathes as used by brass turners are driven directly by a belt to a pulley on the spindle, but engineers' lathes are driven by single gear for the smaller sizes, and double gear up to 18-in. lathes, while treble and even quadruple gear are applied to heavier machines. By these means increased power may be applied, according to the heaviness of the work.

Choice, how determined.

To allow the most suitable lathe to be selected, the purchaser should state the class of work or trade on which the machinery is to be employed, the greatest diameter and length of the pieces to be turned, and whether the work is of a heavy or light kind. Although the height of centres and length of the bed are the main dimensions by which the lathe is designated, these particulars do not alone allow the proper appraisement of value, for if the height of the centre be increased (so as to increase the nominal capacity of the lathe) without increasing the strength of the parts—as in the competition of trade is not unfrequently done for cheapness—the bed, head-stock and other important parts will not be strong enough for the additional weight which the size of the article throws upon them, and the tool will have to work at an unprofitably low speed or depth of cut, or the lathe will be unduly strained or break.

Capacity, how measured.

Wheel-lathes. *See* VIGNETTE, *page* 735. *See also page* 687.

Wheel-lathes are used for turning and boring railway wheels, and are generally made with two slide-rests to operate at the same time on a pair of wheels fixed to an axle. Sometimes there are even four slide-rests, so that a tool can operate at the same time on each side of each wheel. The face-plates can be made to revolve at the same or at different speeds, so that a wheel may be turned on one, while another wheel is bored on the other. As the gauge and diameter of railway wheels vary only within moderate limits, every part of the machine can be made exactly for the purpose in view. Lathes of this kind are also employed as surfacing-lathes for boring out the tire for the wheel and the hole for the axle. Wheel-lathes cost from £250 to £1000, and weigh from 8 to 40 tons, the heavier and more expensive kinds being very powerful for turning large locomotive wheels.

Used as surfacing-lathes.

Multiple-lathes.

Multiple-lathes have two or more parallel spindles, and are made either as turning-lathes or surfacing-lathes. They are chiefly used in those trades where large numbers of articles have to be made precisely alike. Thus in the manufacturing of small steam-engines or pumps, three cylinders or three pump-barrels can be bored, faced or turned at one operation; or screw cutting effected on three rods. Lathes of this sort may be regarded as special tools; they are seldom made except for some particular purpose, for which they are specially designed, and cost more than double the price of ordinary lathes.

Copying-lathes.

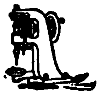
Copying-lathes are those in which the shape is given to the article operated on, by coupling the cutting tool to a blunt feeler tool, which follows the shape of an iron or steel pattern revolving on a parallel axis to that of the article to be turned. These lathes are mostly used for turning in wood, oval hammer shafts, wheel spokes and similar articles.

Special lathes.

Brass-finishers.

Special lathes are made for the various smaller industries which are subsidiary to the engineering trades. Lathes for brass-finishers are generally made of very simple construction, with the mandril revolving at a higher speed than is usual in the turning of iron and steel. Lathes of an ingenious and rather complicated kind are made, in which brass work can be turned and bored either parallel or taper, faced and screwed, without removing or re-fixing the work. Articles can be finished in these lathes to gauge, and interchangeable, at a lower cost than that of the less perfect work done by the old-fashioned methods. Lathes for oval, spiral and other ornamental work are also made, but are not generally employed in engineers' workshops.

Drilling-machines.

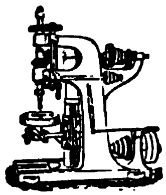


207.

Bench drills.

The *Drilling-machine*, as one of the rudimentary and necessary tools of the metal-worker, was, like the lathe, in use long before the introduction of steam-power. The different kinds may be classed as *bench*, *wall*, *pillar*, and *radial* drills, besides which there are horizontal and other special kinds; the choice among these different machines depending mainly on the size, shape and weight of the article to be operated on. *Bench drills* are small machines which can be bolted down to a work-bench and driven either by hand or power. Hand-machines cost from £5 to £10, and are often used in small factories where there is no steam-power available, or on temporary works. Bench-machines driven by power cost from £8 to £40.

Wall drills.



208.

Pillar drills.

Wall drilling-machines can be used with advantage for articles of small weight and size, so that one man can move them about at the machine, and by its attachment to the wall a machine of this kind is more easily and cheaply steadied than a pillar drill or self-contained machine; and it occupies less room in the workshop. But when articles of wide and irregular shape have to be drilled, the wall would in many cases prove an obstruction, by hindering the article from being turned about and brought into position under the drill, and for heavy work the wall, unless stiffened with buttresses, may not be strong enough. It is for cases of this sort that the self-contained *Pillar drill* is useful, as it may be made of any strength and there is more room around the machine within which to move or adjust the article. The distance from the edge of a casting or other article at which a hole can be drilled, obviously is limited by the distance which the drill projects from the framework of the machine, and this "reach of centre" in a wall or pillar drill is (like the "depth of gap" in a punching machine) one of the leading points deciding the capacity and usefulness of the machine. The wall drill and pillar drill are generally similar in other points than that which their name signifies, and modern improvements in detail have been made in both alike. Better gearing, adjusting-tables, ball or roller thrust-bearings, facilities for attaching the article to be drilled, changes of speed and automatic feed in the advancing cutting-motion of the drill, are the directions in which such machines have been improved, all these points acquiring greater importance as the diameter of the holes to be drilled becomes larger.

Reach of centre.
See page 757.

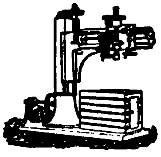
Improvements.

The capacity of a drill may be measured or stated according to the distance the drill centre reaches from the body of the machine, or, in the United States, by the diameter of the article. Thus, a drilling-machine with 24 in. reach would be rated as a 48-in. drill, the diameter and the depth of the hole which it will drill, and the kind of gear. The diameter and depth of hole that can be drilled have also to be considered, for they determine most other points, such as the diameter of spindle, the size of the wheels and the strength and stiffness of the framing to resist the upward thrust from the drill, and also whether single or treble gear is required. Wall or pillar drills of the kind just described are needed even in the smallest engineering factory. A wall machine for holes up to 1½ in. diameter costs from £25 to £50; one for holes up to 3 in. diameter from £40 to £60; and larger sizes up to £100, the necessity for numerous parts and self-acting apparatus increasing with the size of the machine. The above prices include the driving-pulleys and apparatus by which the power is transmitted from the main shaft of the workshop to the particular machine. Pillar drills, as self-contained machines without the need for wall supports, cost generally from about 20 to 50 per cent. more than the wall drills of like capacity.

Capacity of drill, how stated.

Examples of cost.

The introduction of the *Radial* drilling-machine may be deemed the most important improvement in machine tools. Till that time, large castings or other articles which were too wide for the reach of centre of an ordinary drill or too heavy to be conveniently attached to such machines had to be drilled by hand; and in the case of heavy articles in which numerous holes had to be drilled, even if the size and weight did not forbid the use of the machine, the constant moving and adjustment under the drill for each hole was troublesome and expensive. In a radial machine the drill is operated from a projecting



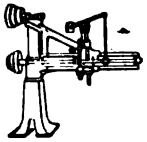
209.

Radial drills.

Mode of working.

arm or jib which swings from the central column or standard of the machine, and within this arm the power is transmitted by a horizontal shaft to the frame containing the drill-spindle, and this shaft, having a continuous slot or key-groove cut in it, the bevel wheels (generally mitre or 45°) upon it can give motion equally at any point in its length to the wheels on the drill-spindle. The swinging arm is sometimes arranged to move vertically on the framing which carries it, the motion in this respect and the transmission of power being effected on a vertical slotted shaft in the same manner as that just described for the horizontal shaft. Not only, however, does the far-reaching arm of the machine allow holes to be drilled at a distance from the edge of the article far greater than the gap of an ordinary machine would allow, but, as the drill can advance or recede along the whole length of the arm, and, when the arm is made to revolve, command any point within the radius, the machine is particularly useful in those cases where numerous holes have to be drilled in the same article, which remains stationary while the radiating arm moves; and the article having been once levelled, any number of holes can be drilled perfectly parallel without any further adjustment, a result which is hardly to be attained with any other machine. The mechanism of these drilling-machines has been greatly improved, the various movements of lifting or lowering the jib, of traversing the drill-spindle along the jib and of swinging the jib, being all controlled by the workman without his having to leave his place by the drill. The machines should tap holes as well as drill them.

Advantages afforded.



210.

Ball bearings.

In a radial drilling-machine it is obvious that there are great strains on the upright framing of the machine from the leverage of the overhanging arm and from the pressure of the drill transmitted through it, and accordingly the connection to the upright framing must, while allowing easy movement, be very firm. The foot of the stem-post should revolve on ball or roller bearings. As the drilling of large holes is apt to cause vibration, it should be avoided at the extreme radius unless the jib is supported at the outer end as presently described. With some radial machines, large base plates are provided for attaching the article to be drilled, but for operating on heavy castings the weight of the article itself resting on the ground affords sufficient stability against the action of the drill. The cost of radial drills varies according to the size and capacity of the machine, to the precise arrangements of the parts and to the extra movements or accessory apparatus which may be needed, and, of course, also

Capacity and speed.

Examples of size and cost.

according to the degree of finish which different services demand or different makers provide. The speed of working is an important consideration, and the drilling of a hole 1 in. diameter through a steel plate 1 in. thick in one minute may be taken as a fair rate. A machine for taking in an article 4 ft. high, and in which the drill commands a space of 4 ft. radius for drilling holes up to 2 in. or for boring with cutters up to 6 in. diameter, costs from £130 to £150, while a machine with 6 ft. radius and for boring holes up to 8 in. diameter costs £200 to £250, such machines, for instance, being those suited for an average engineering works or locomotive factory. Radial machines fixed to the wall and commanding therefore only a semi-circular area, cost slightly less than the above. Much larger machines are, however, constructed for use in marine-engine factories or wherever the articles to be drilled are of a great size. The radial arms or jibs extend 12 ft., and when the drill is working at the end of the jib, the latter is supported by a standard temporarily fitted upon the bed-plate, and having within it a vertical groove within which the end of the jib can slide up and down. Machines of this sort cost from £400 to £500.

Special drills.

Among the special drilling-machines contrived for particular purposes or trades those may be mentioned which drill holes in other than a vertical direction. The radial machine just described is sometimes made so that the drill-holder can be adjusted at any diagonal angle. Horizontal fixed machines also are made for drilling the flanges of pipes, or cylinders, columns and screw piles, which cannot conveniently be brought within the operation of a vertical drill. For the horizontal drilling of boiler shells, four holes may be drilled simultaneously.

Multiple drills.

Multiple drills (several drills on one machine operating at the same time) are employed where a large number of holes are required in regular order or sequence, such a multiplication of drills allowing not only a saving of expense but—unless a large number of machines were employed—a great saving in time also. Such cases occur, for instance, in wrought-iron or steel girders, if drilled rivet-holes instead of punched holes be required. Boiler-plates in like manner afford opportunities for multiple drills; also tubulous boilers or the tube-plates of tubular boilers or surface-condensers. As in work of these kinds there are certain usual distances apart of the holes (from 3 in to 6 in. apart, embracing those most usual and useful) there is repetition enough to render the construction of special tools profitable.

Multiple drills have been designed in various ways, partly to meet varying necessities and partly because of differences in method. For

Drills for girder-work.

girder-work the general arrangement resembles that of a planing-machine, the table on which the article to be drilled is placed moving between a transverse framework carrying the drills. The drilling-spindles are generally ranged in line across the machine, and are operated from one shaft either by a screw and worm-wheels or by bevel gear. The precise methods of working differ considerably, and some machines offer more facilities than others for quickly adjusting or disengaging the drills. In all machines the pitch or distance apart of the holes can be varied within certain limits, the distance depending on the width of the tool-holder, the maximum distance being only limited by the width between the standards. If, as in a girder plate,

Varying pitch of holes.

six rows of holes have to be drilled to a pitch of 4 inches, six drills work side by side, and the moving table moves forward 4 inches from time to time. A pitch of 3½ in. is the minimum to which these drills can be applied. If a single row of holes only is required, as in a bar, then it is endeavoured to utilise as many drills as possible by placing numerous bars side by side. Time is saved by placing numerous plates upon one another, and drilling through all the thicknesses at one operation. In such a case one plate may with advantage be drilled first and placed at the top and used as a template or guide for the drill, no spacing or marking of the lower plates being then

Drilling through numerous plates.

necessary. The drilling through numerous thicknesses not only increases the effective service of the machine but ensures accuracy of work where two or more plates have—as often happens in girder-work—to be riveted together, for, when each plate is drilled or punched separately, it is impossible, even with the greatest care, that the holes shall absolutely coincide. Multiple drilling-machines may be driven by belting in the ordinary way, and such machines cost

Examples of cost.

from £100 to £400 each, and weigh from 2 to 12 tons, but it is often convenient to make the machine independent of the general running shaft and to attach a small steam-engine or electric driver to the machine; an additional cost being then incurred of about £50. Special machines are made to drill horizontally the rivet holes in boiler shells or flues while hanging vertically before the machine.

Groups of radial drills.

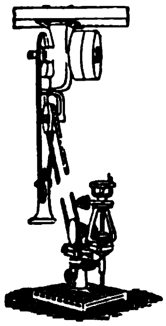
Multiple drills, as above described, have been largely superseded by a group of radial machines which command a wide area and allow numerous drills to be used at the same time on one piece of work. Portable multiple drills have been devised for drilling the main booms or members of girders when erected in place, the various thicknesses of steel that have to be united not having till then been placed together, so that the drills can pierce through all in the manner considered desirable for ensuring the desired coincidence of the holes. Drills of this sort to be serviceable must be strong, and they cost about £300, but have not been very widely adopted.

Drill-posts.

Portable drills.

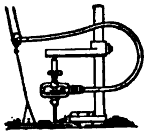
Mode of working.

Drilling has often to be performed in situations inaccessible to any of the machines just described, and in such cases it has been usual to fix a "drill-post" or light frame on or near the article to be drilled, and by means of a ratchet or swing brace attached to the post to work by hand: such process, however, being tedious and expensive. The necessity for manual work of this kind has for the great majority of cases been rendered unnecessary, for by an ingenious invention the power from the main shaft of the workshop can be transmitted at any angle and to a varying distance to a drill-post where the drill (adjusted and controlled by the workman as with the ordinary hand-drill) operates with all the advantages of mechanical as compared with manual power. But the best application is that in which the drill-post is equipped somewhat like the arm of a radial drill with a traversing screw and feed gear, so that when the post is clamped to the work, all the advantages of a drilling-machine are obtained. Instead of a belt, a hempen or cotton rope is used to transmit power to the machine, and the pulleys over which the rope runs being made to revolve on a swivelled frame, the running rope can be taken in any direction. The tightness of rope necessary to transmit the power is obtained, not as with a belt by making and maintaining the rope of an exact length, but by suspending to it a weight. It will be seen, therefore, that according as the drill-post, with the power-receiving pulley round which the rope runs, is more or less distant from the power-giving pulley, the weight rises or falls, always putting a sufficient strain upon the rope. During the drilling of large holes the weight can be increased to prevent the rope slipping upon the pulley. A complete apparatus, including the drill-post with the necessary gear, costs from £35 to £50, the novelty consisting in the swivelled pulley-frame and suspended weight.



211.

The machine just described is of course only applicable in cases where no obstacle interposes between the power-giving shaft and the drill-post, although, if the occasion were of sufficient importance to warrant the construction of the necessary pulley-apparatus, the ropes need not move in one direct line, but might be conducted round corners. But it is obvious that there are many parts and angles of ironwork or machinery in course of construction where holes are needed quite inaccessible to such an apparatus, and hand-drilling seems the only resource. But by the use of "flexible shafts" power can be transmitted round corners in a manner which appears remarkable. It has been discovered that by a peculiar arrangement of spiral wires, held together in a tube or sheath of leather, a revolving motion can be transmitted a considerable distance with very little friction, even although the shaft or axis be turned or twisted in several directions. Thus, such a flexible shaft can be taken in at the manhole of a boiler to a drill working at a remote corner, or to places as apparently inaccessible. The complete apparatus, including 8 feet of shaft, costs from £10 to £30.



212.
Drills with flexible shafts.

Electric machines.

The small machines just described have been to some extent superseded by electric machines. For where an electric transmission system has been established in a factory, great facilities are afforded by it for the use of portable drills. Machines in which a small electric motor or "driver" is attached to the drill-spindle can be moved from place to place on the side of a ship under construction, or of a bridge in the building yard, the power being transmitted by a light flexible conductor. The driller is held to its work by electro-magnets, and needs no mechanical attachment.

Attached by magnets.

Balanced spindles.

The economy and usefulness of a drilling-machine depends greatly upon its speed and on the suitability of the drills which do the work. Vertical spindles should be so balanced as to put no undue pressure on the tool as the hole approaches completion and so that it will run back quickly and easily when the hole is finished. The vertical thrust of the drill-spindle should be taken on ball bearings. A useful accessory to drilling-machines of all kinds is afforded by the *Twist-drill*, which may be considered as one of the most valuable minor inventions which have been introduced in machine tools. It is superior to the ordinary drill in that, instead of being smaller above its point, it is parallel its entire length, and therefore it forms a correct guide for itself to bore a straight hole, and for the same reason it is the best adapted of any form of drill for running in the holes of a previously drilled template, which will guide it through a succession of plates so as to make them exact counterparts of the template. The twist-drill cuts out the substance as a shaving, which escapes through the spiral groove; and it maintains its diameter to the end.

213.
Twist-drills.

Mode of working.

The twist-drills, however, demand special skill in their manufacture, and cannot, like ordinary drills, always be made by the users. The points are tender, and it is important that the drill-spindle in which they are used should be balanced or counterweighted as above described, so that there may be no drop when the drill begins to break through the bottom of the hole. It is essential that the drills shall be ground quite truly, and special grinding-machines are sometimes used for this purpose, a usual plan being to cut the spiral grooves with a milling-machine. It is also very important that the drills shall run truly, and to ensure this, the shanks of the drills are turned taper round (a taper of 1 in 20 is most effective) to fit exactly into a conical socket-hole. By this arrangement the point of the drill revolves truly in the same axis as the spindle; the drill can be quickly put in and taken out of the machine; and drilling can be much more quickly performed than with ordinary drills. But while the twist-drills ensure quick and accurate drilling in the manufacture of such exact works as engines and machinery, some users find a simple drill, aided by a water jet, effective for such drilling as is required in girders or boiler-plates. These drills are of a form which allows the shavings of metal to escape, and by means of a small tube, a jet of water in fine spray is ejected on to and around the point of the drill. The water should have a pressure of not less than 50 lbs. per square inch, and if this be not obtainable from an existing water-main or pipe, a small pump (worked by the shafting of the drilling-machine itself) should be provided for the purpose.

Mode of making twist-drills.

Water-jet for drills.

Pressure-water.

Gauges are principally used for the best class of drilling, and the workman is no longer allowed to regulate the size of his drill and test its operation merely by the callipers and measuring-rule. Standard plug-gauges of great exactitude are obtainable, and are specially essential where repetition or interchangeable parts are manufactured.

Gauges.

Standard plug-gauges.

Although holes may be drilled with great exactitude by the machines which have been described, other processes are necessary for a bore of large diameter, and also where large holes have not to penetrate right through the substance operated on. Much boring is effected on the chuck of a surface-lathe, and with a cutting-tool worked from an ordinary slide-rest the operation may be classed as internal turning, as the tool is stationary while the article to be bored revolves. Another kind of boring is that in which the article is fixed on the lathe-bed or boring-mill, and a mandril or boring-bar,

Boring holes on chuck-lathes.

Boring-mill.

held only at one end by the chuck, enters as far as needful, the mandril with a cutting-tool upon it travelling forward, or the tool moving along the mandril by a self-acting arrangement. Such a method is useful for boring large or heavy castings which cannot

Mode of working.

conveniently be attached to a revolving chuck. Where however the hole passes right through a long casting it has been deemed preferable to use a boring-bar or mandril, supported at both ends; and so convenient is this method that a hole right through the casting is sometimes made temporarily (and afterwards plugged up), even where the bored hole is limited only to a portion of the length. Resembling lathes in many respects, machines devoted to this special purpose are known as *Boring-machines* or *Boring-mills*, and are used for boring out steam cylinders, pump barrels, and other similar articles, the interiors of which, already approximately correct from the foundry mould, have to be bored truly cylindrical, an operation more conveniently effected in a special machine than in an ordinary lathe, although the latter can be generally used if desired. Boring-machines range from 10 to 20 ft. long, and have a bed and head-stock somewhat like those of a lathe. The cylinder to be bored is adjusted on the bed-plate, to which it is firmly fixed, and the boring-bar or rod of the machine—in effect a large mandril—passes right through it.

Tool-holder on mandril.

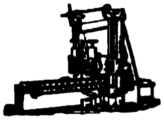
Upon the rod is a disc-shaped tool-holder with one or more projecting cutters, and as the bar revolves and the cutters operate, the disc is made to advance by a screw within the bar, till the cutters have bored out the entire length of the cylinder. The desired smoothness of surface is given either by a succession of operations or by placing two or more tools on the travelling disc, so that following close behind each other, two, or perhaps three, cuts are given at the same time.

Boring of large cylinders.

The boring of large cylinders sometimes occupies many days, and it is not unusual for the machine to be kept in operation without any stoppage till the work is completed. In a boring-machine of the kind just described there is a longitudinal or "end-on" pressure of the bar against the head-stock, and during a heavy cut, unless this pressure is received on ball bearings, the friction is excessive and the bearing place is with difficulty kept cool and lubricated. Boring-machines, such as are used in an engineer's factory, range in price from £150 to £300. Vertical machines of great power are employed to bore out large marine cylinders, and such machines cost more than horizontal machines.

It is an objection to large machines of the kind just described, that the mandril or boring-bar is apt to bend slightly under the strain of a heavy cut, the bore under such circumstances not being quite parallel. To meet this difficulty the "snout" machine has been contrived in which the boring bar is held in solid bearings.

214.
Snout boring-machines.



215.
Planing-machines.

Mode of working.

Cutting-tools and tool-holders.

The introduction of the *Planing-machine* was the first in a series of inventions which have since furnished to the manufacturing engineer entirely new kinds of tools. Till that period, surfacing which could not be performed in the lathe had to be laboriously effected with the chisel, file, and scraper; the facing of slide-valves and similar work by these means occupying much of the time of the best mechanics, and was even considered a leading test of their skill. In almost all planing-machines the tool is fixed, and the article to be planed travels, and in the earlier machines the motion was given to the table by a rack and pinion. The alternative method of a quickly-running screw was introduced later; and subsequently a combination of rack with worm-wheel was considered most effective. A cutting speed of 20 feet per minute may be maintained with well-made machines and continuous lubrication, and with single-acting machines the return speed should be 60 feet per minute. The power absorbed by such a return motion, is, however, double that needed for the cutting, and a better effect is obtained by using double tool holders, by which an effective cut can be taken on the backward as well as the forward stroke of the machine. There are different modes of effecting this, and assuming that a planing-machine is well designed in all other respects, its output capacity or earning power depends on the proper disposition of the cutting-tools and tool-holders. Great ingenuity has been displayed in this direction, and up to the year 1898 it may be said that the arrangement of two cylindrical fulcrum tool-holders in one box is most effective for general engineer's work.

Capacity, how stated.

Long-stroke machine.

The capacity of a planing-machine is stated by the dimensions, which are those of the width between the uprights, the height below the saddle, and the length of the tables; these dimensions, of course, determining the size of the article that can be brought within the operation of the machine. Thus a machine will be designated as 3 ft. by 3 ft. by 10 ft. long. The length of the article is not, however, bounded by the length of the table, as it can be made to overhang it, and, if the length require it, be supported on rollers or trestles. To allow this, ample floor-space should be provided at each end of planing-machines, and if the workshop be otherwise too small, doors are generally provided so that long pieces can project beyond the workshop, thus giving full scope to the travelling table and its contents. The machines referred to below for planing the edges of girder-plates or boiler-plates afford an example of this method.

Examples of cost.

The great proportion of the planing-machines used in engineering factories range inside from 5 ft. long by 2 ft. wide by 2 ft. high, costing from £90 to £130, to those which are 20 ft. long by 8 ft. wide by 8 ft. high, costing from £500 to £1000. Between these limits machines of all sizes can be obtained, although each maker has patterns of precise sizes which he prefers to supply. Sizes both smaller and larger than the above are occasionally made, but small planing-machines have been generally superseded by the more modern shaping-machines. It is most important that planing-machines be strongly and accurately made and solidly fixed, for while yielding or inequality will, in any machine, involve risk of untrue work, such risks are in a planing-machine increased by the number of jointings and moving parts which interpose between the levelled base of the machine and the cutting-tool.

Concave or convex planers.

Plate-edge planers.

Planing machines can be adapted by special arrangements for concave or convex work, and by means of templates, which give a transverse or vertical movement to the tool as the table advances, varying curves can be produced; this latter operation being, for instance, often required in the planing of armour-plates for war-ships. A special kind of planing-machine is used by bridge-builders and boiler-makers for cutting the edges of plates (several plates being generally clamped together and operated on at the same time), and these machines are generally arranged with double tool-holders, so that a tool is in operation both in the forward and backward movement. Hydraulic holding-down "jacks" form a convenient adjunct to these machines, which with such facilities can be made to plane plates as long as 30 ft. which may be buckled or bent. It is, of course, necessary that the maximum sizes to be operated on be known to the maker; for if necessary, by a different construction of the machine, the plates can be then passed forward and a second 30 ft. planed in a continuous length. In some cases by this arrangement a shorter machine may be used for general work, as the effective length of the machine can be doubled or trebled. A cost of from £200 to £400 will embrace the great variety of plate-edge planing-machines. Vertical planing-machines, having a vertical and

Vertical planers.

horizontal movement for operating on large masses, are made chiefly for the use of marine engineers, but as in these machines the tool and not the article operated on travels, they may be more correctly classed as slotting or shaping-machines; the space occupied is much less than in horizontal machines, and big work is set more cheaply.

Shaping-machines.

The *Shaping-machine* was an outcome of the slotting-machine and planing-machine, and may be considered, if not a final triumph of ingenuity, yet as filling the want long left unsatisfied by the other machine tools, the chief utility and labour-saving of the shaping-machine being shown by its operating in positions inaccessible to the lathe and ordinary planing-machine. Long after slide and face-lathes had been brought to a high state of efficiency, much important work had to be left to expensive hand-labour; but there are now few parts of a steam-engine which cannot be operated on by machinery. Such awkward shapes as a cross-head, a curved link, or the open-jawed end of a rod, can be pared and shaped over the entire surface by the machine tool. Where a curved article has to be cut, the article can—if the radius be within the compass of the machine—be fixed on a central table or on a central arbor or mandril independent of the table, which is made to revolve automatically, so as to press forward the article the thickness of one cut at each stroke, against the tool held in a moving arm. In this way incomplete circles to which the lathe cannot be applied are cut, and sometimes the machines are made with two tables and two moving arms. Circular work has been facilitated, both on slotting and shaping-machines, by adding a dividing apparatus to the table, so that the teeth of wheels can be accurately cut from the solid, as is done in a wheel-cutting machine. Shaping-machines are generally made with a horizontal movement, the name of slotting-machine being retained for those with vertical movement. Shaping-machines are generally classed among the smaller tools of an engineering factory, although large ones may be made for special purposes. A range of price from £50 to £200 will embrace nine-tenths of all that are made.

How employed.

Will cut awkward shapes.

Circular work.

Cost.

Slotting-machines.

Slotting-machines may have a vertical motion only, and might be described as shaping-machines placed on end, as the tool and not the article to be operated on moves. Slotting-machines can be either attached to the wall of the factory or made independent; they are employed for cutting key-ways, or for cutting out masses of metal, as

Range of, size and cost.

in crank-shafts; and they are thus useful for many operations inaccessible to the drill, lathe or planing-machine. They are made of all sizes up to the massive machines with a maximum stroke of 15 ft., used by marine engineers, costing sometimes as much as £2000; but for ordinary engineers' work the cost of slotting-machines ranges from £50 to £500.

Compared with shaping-machines.

For heavy cuts, the slotting-machine is preferable to the shaping-machine, as in the latter the cutting-tool presses the work away from the bed. Information as to the nature of the trade, and the size of the pieces to be operated on, is necessary to a proper choice of planing, slotting or shaping-machines. These machines resemble each other in that the length of traverse can be varied, and that the return stroke is quicker than the forward or cutting stroke.

Milling-machines.

Revolving cutters.

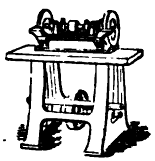
Substitute for shaping-machines.

Revolving discs with inserted teeth.

Milling-machines, in which metals are operated upon by serrated rotary cutters, work more effectually and cheaply in certain cases than shaping or slotting-machines. Milling-machines are used for cutting spiral or straight grooves or notches, and when these are of moderate size, a revolving tool will, as it advances, cut away the entire width. The kind of work to which these machines are applied may be exemplified by the cutting of slots in hinges or the teeth of wheels or the key-ways in shafts; and in the manufacture of small-arms, clocks and watches, milling-machines are indispensable. Although used principally for small operations of this kind, special milling-tools have been made for cutting out the slots of locomotive crank-shafts, and it is applied with success as a substitute for the planing-machine in cutting level surfaces of moderate area; but the use of milling-machines for cutting large surfaces is of doubtful advantage. Where milling-machines take the place of small shaping-machines, the spindle carrying the serrated cutter is linked to a parallel spindle having a blunt or feeler tool working against a pattern of the article to be made, and after the manner of a copying-tool, the cutter follows automatically the form of the pattern, and bites away the metal more quickly than by the repeated cuts of the tool of an ordinary shaping-machine. Revolving discs with loose adjustable cutters, or which may be designated as cutters with inserted teeth, can be used in the milling-machine for certain operations with greater advantage for large work where the ordinary serrated cutter is costly to make and maintain; though these might even be designated as revolving planers. Milling-machines cost from £100 to £500, according to size and to the number or variety of accessories.

Useful for repetition work.

Milling-machines show to the best advantage in repetition operations and in the similarity of the work produced, as the width of cut does not depend on the action of the workman. The making, hardening and tempering of the serrated cutters together form one of the principal expenses in the working of these machines; but the cutters can be made by the ordinary skilled workmen of an engineering factory, and many of them may be shaped by the milling-machine itself.



21

Emery-wheel grinding-tools.

How employed.

Emery-wheel grinding-tools are used with great advantage instead of cutting tools in many operations where a smooth, but not an absolutely true, surface is desired. Thus emery-wheels while mostly used for fetling or trimming small castings, dressing forgings, cleaning wheel-teeth and for sharpening saws, are also employed with advantage for making true the joint faces of castings which are too light to endure chipping or even planing. For grinding and sharpening various kinds of knives and cutting-tools, the emery-wheel may in some cases be substituted with advantage for the grindstone. The emery-wheel will also finish the surface of chilled castings, or case-hardened ironwork or tempered steel which are too hard for the file. The machines in form somewhat resemble a lathe, having like it an iron bed or framing (but much shorter than a lathe bed), with a horizontal shaft, upon which is fixed the emery-wheel or disc; but there are numerous varieties in the form of machine; many are made for special purposes, and some are automatic in their action.

Emery discs.

Size and velocity.

The emery discs or wheels are made of a peculiar composition, so that they wear slowly and equally, and are of various diameters, from ½ in. to 36 in., and of thickness to suit the nature of the work or shape to be produced. The discs run at a high velocity (from 5000 to 7000 periphery feet per minute being usual speeds), and cut away the metal presented to them very quickly. For most purposes the discs work dry, but for tool-grinding and similar operations they revolve in a trough of water. The emery-wheel is useful in many cases for giving a smooth surface to articles—such as thin pulleys—too light to endure the pressure of a cutting-tool in a lathe; and as preparatory to or as a substitute for the finish of a file it saves much expense in hand-labour. The simple machines cost from £3 to £30 each; but the more elaborate machines of larger size, with slide-rests and other adjuncts, range in price from £30 to £70 each. The emery-discs weigh from ¼ lb. up to 600 lbs. each, and cost from about 1*s.* per lb. for large sizes, up to about 2*s.* per lb. for very small sizes. Although in the majority of cases very great mechanical accuracy is not attempted, emery-machines are occasionally used for very exact work, such as the slide-bars of horizontal engines, or other work that has to be made true after it has been hardened by heating and quenching. For work of this sort the machine with its appurtenances will weigh from 5 to 10 tons, and be necessarily much more costly than those described above.

How used by engineers.

Screwing-machines.

Screwing and tapping-machines are necessary tools in an engineering factory, for although the manufacture of bolts and nuts is a special branch of trade, and engineers often purchase them ready-made, there are many cases when the screwing must be done in the factory. In Great Britain, the Whitworth standard thread is universally adopted, but in America the thread, while mainly following the English pattern in regard to the proportion of pitch or coarseness to the diameter, differs enough in shape to prevent interchangeability with English screws.

Standard thread.

There have been numerous improvements in the methods of cutting screw-threads, so that one workman can in a given time produce more and better screws. Formerly the thread could be formed only by a succession of cuts; now it is formed at one cut.

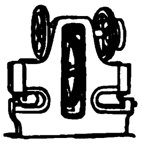
Tapping-machines.

Machines are usually made both to screw bolts and tap nuts, but where large quantities are made, as in a nut and bolt factory, separate machines are employed. Although in the same machines both large and small sizes can be screwed, and such a machine may be convenient for a small factory, it is better generally to narrow the range of sizes and to have more than one machine. Thus one machine, costing with all accessories £60 to £70, may be used for all diameters between ¼ in. and 1 in., while a stronger machine, costing about £100, might include all diameters between ¾ in. and 2 in. Diameters larger than 2 in. have generally to be cut in a lathe, but by improved machines, screws up to 6 in. diameter, with either vee or square threads, are cut at once very exactly. These machines are, however, expensive, and cost about £100 per inch of diameter, and such an expense is only justified where numerous screws of large size have to be made, the saving over lathe-work in such cases soon repaying the greater outlay. Quick speed rendered possible by forced lubrication with lard oil is essential to cheap working in modern screwing and tapping-machines.

Range of size and cost.

Cold saws. *See also* HOT SAWS *page* 785.

Cold saws, with a periphery speed of about 60 ft. a minute, are used with advantage for cutting the ends of L and other bars when a smooth exact surface is required. Horizontal saws are used for trimming the edges of flanged plates.



217. Punching-machines.

Punching-machines, for making holes in cold steel or wrought iron, are among the most useful and necessary machine tools, and some trades may be said to be entirely dependent on them. For punching the softer metals, such as copper and zinc or thin sheet iron, hand-presses are sufficient, and are used in large numbers. In these the descending punch is operated by a screw, which is turned by a handle loaded at its ends, or by a wheel with a heavy periphery to act as a fly-wheel, which by its latent or stored energy will force the punch through the metal. In the larger machines used by engineers, the punch is generally operated by a lever and cam, or by an eccentric (a steady motion being ensured by a fly-wheel), these being convenient methods for the short stroke required.

Capacity, how stated.

The capacity of a punching-machine is expressed by the diameter of hole and the thickness of the plate which can be punched by it; and these two circumstances have to be considered together, for it is difficult to punch small holes through thick plates, the diameter of hole practicable in machines of the ordinary kind being approximately the thickness of the steel. But while the force necessary to the operation may be thus determined, the value of the machine depends also on the *Depth of gap*, or that distance outward from the framing which the punch projects. But while with a deep gap holes may be punched a considerable distance from the edge of a plate, the strains upon the framing of the machine, always severe during the operation of punching, are intensified according to the leverage of the overhanging arm; and therefore the necessary strength, weight and cost of the machine increase in a growing ratio as the gap is widened.

Depth of gap.

Shearing-machines.

Punching-machines are generally provided with a shearing apparatus, because the design of the machine and the order of working facilitate the double operation, and because also the trades which require the one process almost invariably require the other also. Small punching-machines limited to holes ½-in. diameter through ½-in. iron plates, or holes ⅝-in. in diameter through ⅝-in. plates, and with a shearing apparatus for ½-in. plates, weigh about 20 cwt., and cost from £35 to £50; while a powerful machine, such as is used in

Examples of combined machines.

a bridge-building factory, capable of punching 1-in. holes through 1-in. plate, at a distance of 20 in. from the edge, and of shearing 1-in. plates, would cost from £200 to £250, and weigh about 8 tons. Larger machines for punching and shearing 1½-in. steel, 30 in. from the edge, cost about £500. It is customary in the best punching and shearing-machines to provide also a special or third apparatus for cropping L bars, this adding about 15 per cent. to the cost of the machine. Special machines for shearing and punching L bars only, are made for ship-builders. Steam-engines are often attached to and form part of large punching-machines, this being in many cases more convenient than the alternative plan of transmitting the power by pulleys or gearing, but compressed air or the use of an electric motor on the machine is likely to supersede this method.

Special bar-cropping machines.

For the shearing of large plates, separate machines without any punching apparatus are generally used, and the manipulation of such plates in presenting them to the shears is facilitated by bringing them to the machine on carriages with castor wheels, transverse and other motions, sometimes provided with roller or ball bearings.

Carriages for shearing-machines.

Modern improvements.

Various improvements have been made in punching and shearing machines. The shape and dimensions of parts are better adapted than formerly for withstanding the stresses and shocks of working, and allow therefore the most economical application of material to the framing of the machine. The methods of transmitting the power to the punch or shears have been improved; and controlling apparatus of a simple kind has been introduced by which the workman, while adjusting the plate or bar to be punched, can instantaneously render effective or inoperative the power of the descending punch; and for particular trades this controlling mechanism is applied to the shearing blade also. Some punching-machines are provided with self-feeding apparatus, by which the holes are made at regular intervals automatically.

Automatic machines.

Accuracy, how ensured.

The operation of punching requires considerable care, but good workmanship depends also on the condition of the machine. It is important that the machine be powerful enough to overcome without difficulty the resistance of the steel or iron operated on; secondly, that the die be accurately and firmly fixed so as to receive the punch squarely and without any yielding; and thirdly, that the sliding parts should fit closely, for otherwise the hole which is being punched will be distorted and the iron or steel damaged. Moreover, unless there be very great accuracy in the fitting of the punch and die, the latter must

Adjustment of punch and die.

be made larger in proportion to the punch than is compatible with good work, and the punch will be apt to diverge laterally from the vertical line and damage the material. The tighter the fit of the punch into the die the better will be the work done, but the greater will be the strain upon the material, so that not only good tools but iron or steel of good quality is needed to ensure good work. It is mainly owing to the want of knowledge or care in these respects, and the consequent bad results, that some engineers forbid punched holes altogether, and require drilled holes. The reasons adduced in favour of drilling are that greater accuracy is obtained, and that the steel is not damaged as by punching, but in good iron the damage need not occur, and in steel it can be neutralised by rymering out the holes after punching, or by annealing. A punched hole is always taper, while a drilled hole is parallel, an advantage in the majority of cases.

Punching *v.* drilling.
See page 560.

Taper and parallel holes.

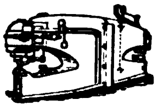
To ensure accuracy in the position of the holes, it has become usual to mark them with a centre-punch, instead of in the more usual manner with colour only, and the punch of the machine is armed with a projecting point or nipple which fits into the centre spot or mark. But marking is altogether avoided sometimes by the use of the automatic feeding apparatus, which so regulates the movement of the pieces to be operated on that the holes are made at regular and prescribed intervals. This method is adopted, for instance, in machines of a peculiar kind, more often used in America than in England, in which numerous punches work simultaneously; the machines somewhat resembling in appearance a plate-shearer or a multiple drilling-machine, the punches being arranged on a cross-slide over a travelling table.

Marking for punched holes.

Automatic feed.

See page 746.

Hydraulic power has been applied to punching and shearing machines, the concentration of force rendering possible the direct action of a ram upon the punch without the necessity for cams, eccentric, fly-wheel or rotary motion, but this method is too slow for general work. Hydraulic power is universally applied to the flanging and dishing of steel plates for boilers or for the corrugated plates for bridge floors. Hydraulic machines of any kind obviously find their best place in a workshop where hydraulic power is established for general purposes, because the pumps and accumulator can be provided on a large scale; but as the pumps may be easily worked from ordinary shafting, and a small accumulator is not expensive, one or two hydraulic machines can be established without inordinate expense.



218.
Hydraulic punching-machines.

See page 493.

Portable machines.

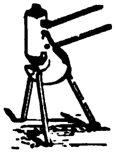
For portable punching-machines, hydraulic power compares still more favourably, and indeed renders possible operations which are quite unattainable by other means. The small screw-punch, or "bear," was formerly the only tool available for this purpose, the power being laboriously applied by a long handle or lever; but even the ingenious duplex adaptation of compound levers for this purpose, by which the long handles are rendered unnecessary, is not so efficient as the hydraulic machine. Portable punches as above described are made either on tripod stands, for work that can be brought to them, or without stands, so that they can be carried to girders or other structures and applied in place.

219.

Punching bear duplex-lever machines.

Screw punches.

The simple screw-punching bears cost from £3 to £5 each, and weigh from 25 to 90 lbs., and the duplex machines, which are much more easily worked, cost from £8 to £14, or, if fixed on a stand for punching larger holes, £30. Portable machines of this kind are most effectual for small holes, and they are applied with difficulty for heavier work than ¾-in. holes through ½-in. iron. But for holes in narrow bars such as rails, where the die can be held at both sides, 1 in. through ¾-in. iron or ½-in. steel can be punched by portable screw-machines. Hydraulic punching-bears cost from £10 to £30, and weigh from 70 to 400 lbs. The weight and cost of all portable punching-machines increase in a rapid ratio if a wide gap is required as previously described.



220.

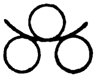
Hydraulic punching-bears.

Small holes may be punched through thick iron or steel by special machines contrived so as to apply the theory of the "flow of solids." It is in this way that thick nuts with small holes are punched cold, as a persistent pressure of the punch in a peculiar way forces the pellet before it.

Size and cost, how determined.

The particulars which determine the form, size and cost of a punching-machine, are the nature of the trade, the maximum diameter of hole to be punched, the thickness of the steel, and the depth of the gap.

Plate-bending machines, for bending the plates of boilers or ships, are made with three rollers, and the plate being passed below the top roller the desired curve is given by lowering it between the two under rollers, so that the centre of the plate being pressed downwards in passing through, the ends curve up. The machine should be so contrived that the upper roller is raised and lowered by power and not by hand, and that the plate after being bent can be



221.

Plate-bending machines.

Horizontal bending-rolls.

Cost and weight.

removed endways, this being necessary when a plate has been bent to a complete circle. Plates have to be bent so for the flue tubes of boilers, and sometimes also for the shell of the boiler itself, in cases where it is sought, by using one large plate, to avoid a seam at the bottom of the boiler. It has therefore become usual to make horizontal bending-machines with the upper part of one standard loose, so that it can swing back and allow the plate to be drawn edgeways from the rollers. While, however, this plan is effective for plates of moderate size and weight, heavy plates, such as are used in ships and for large marine boilers are too unwieldy to be so moved, and to meet these cases machines with vertical rollers are made, in which plates up to 5 tons weight can be treated. Such machines cost from £1000 to £1200. Ordinary plate-bending machines range in length from 6 ft. to 10 ft., cost from £150 to £250, and weigh from 5 to 10 tons, the weight and cost of the machine being determined as much by the thickness of the plates to be bent as by their size.

Riveting-machines.

Steam machines.

Riveting-machines are made either for steam or hydraulic power, and in both the pressure is applied directly without the interposition of wheels or gearing. In a steam machine, a horizontal cylinder of large diameter is employed, so as to concentrate a sufficient power on the piston-rod forming the rivet-closer. Riveting-machines have to stand a considerable height from the ground to allow structures of varying shape and size to be presented to the riveting-tool. The weight and strength of the framing, and therefore the cost, depend more upon the depth of gap than upon the diameter of the cylinder. The prices of steam riveting-machines as used by boiler-makers and bridge-builders range from £250 for a machine with 3-ft. gap, £300 for 4-ft. gap, to £450 for 6-ft. gap; the weight ranging from 8 to 15 tons. The above prices are exclusive of the overhead crane.

Machine and hand-riveting compared.

See also STEAM-HAMMERS, *page* 777.

Heating of rivets.

The superiority of machine over hand riveting lies in the different effects which result from the different kind of blows. A small weight falling with a considerable velocity a great number of times may produce the same aggregate result as a heavy weight falling once with a less velocity, but the effect worked by the former is chiefly in the particles nearest to the tool (the hammer, the rivet-point, and the surface of the plate), while with the latter the effect is transmitted to the more distant or interior particles. A rivet should be heated throughout its entire length, and when inserted should be as hot—and for hand-riveting, or in the case of long rivets, hotter—at the head as at the point. The blows of the hammer are not felt so severely at the hilt as at the point, and as at both it is necessary to swell out or "upset" the rivet to fill the hole entirely, extra heat and ductility at the hilt allow the blows of the hammer to have due effect.

Imperfect hand-riveting.

The effect of hand-hammering on a rivet depends on the care and skill of the workmen. If they strike the rivet flat several times, they will "upset" the iron and fill the rivet-hole, but they do not always do this effectually, but begin to form the head prematurely by striking the rivet at an angle, trusting to the cup, or snap-tool, to upset the iron in the hole, which it does not do effectually. A riveting-machine avoids this defect, and moreover has the advantage of pressing the plates, through which the rivet passes, together. Hammering, if continued too long after the rivet begins to get black, causes the iron to crystallise, and rivet-heads so formed are brittle and often fall off. Steel is more liable to this than good iron, and for this reason high-class iron rivets are often used, even for steel boilers. Where very ductile iron or steel is used, rivets not exceeding half an inch diameter may be hammered quite cold.

Quality of iron and steel for rivets.

Steam-riveting machines are useful for all but the heaviest work, as a machine of moderate size with a piston of 36 in. diameter can, with an effective pressure of about 50 lbs. to the inch, give a total force on the rivet of 22 tons. In using such machines, however, it must be noted that any reduction of the steam pressure will at once diminish the force on the rivet, and so produce irregular work.

Amount of force to close rivet.

Hydraulic riveting.

Hydraulic power finds a useful application in riveting-machines, and in the opinion of many engineers offers such advantages over steam power as to induce them to prescribe hydraulic riveting for all rivets over a certain size. The operation may be described as a blow and squeeze combined, and to obtain the necessary velocity the power must be brought through the medium of an accumulator, a direct supply from the pumps to the machine not being quick enough. Hydraulic machines are particularly useful for rivets of large diameter passing through numerous plates, as the great force which may be applied closes and holds the plates together in a manner otherwise unattainable. Where there is a complete system of hydraulic machinery, a special steam-engine for pumping is provided; but for one or few machines, the pumps can be worked by belting from the general shafting of the factory or by an electric motor, and the expenditure for power so abstracted is less than that taken from a boiler for a steam-machine. There is also the advan-

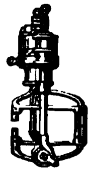
Blow and squeeze combined.

See page 493.

tage that pressure-water may be brought a considerable distance from the source of power without appreciable loss. Hydraulic machines weigh from 5 to 10 tons, and cost from £150 to £500 exclusive of pumps and accumulator. The machines are generally made to exert a force of from 25 to 50 tons on the rivet-closer, and the gap of the machine can be made of any depth from 4 ft. up to 12 ft.

Weight, cost and power of machines.

The *Portable hydraulic riveter* exemplifies the peculiar advantages of water-transmitted power more than any other operation to which it has been applied. By means of a machine measuring about 20 in. by 30 in., and weighing only from 300 to 500 lbs., a pressure of 30 tons can be applied to the closing of a rivet in its place as part of a large structure—girder, bridge, ship or boiler—which would be quite inaccessible to a fixed machine, and without such a method, only to be performed by hand-labour. This concentration of power in a small compass is rendered possible by the high pressure which can quickly and easily be obtained from hydraulic pumps through an accumulator, and to the simple and effective jointing or articulation of the small tubes through which the water is conveyed, and which allow the machine to be moved from place to place almost as readily as a portable gas-lamp supplied by a flexible tube. It is in its mobility, and in the quick stroke which the accumulator affords, that the portable riveter differs from the hydraulic lifting-jack, for in both the force is obtained in a small portable machine by the use of high-pressure water on a piston or ram of small diameter. A hydraulic riveter as just described costs only about £100 if used where hydraulic pumps and accumulator are already established, but an additional cost of from £170 to £200 must be incurred if these have to be added. This is still exclusive of the engine power for the hydraulic pumps, which can however be generally worked from an existing line of shafting, with an expenditure for the force abstracted much less than that which would be required in wages for hand-riveting. The cost of overhead cranes or travellers has generally to be incurred, the kind and cost depending on the nature of the work to be operated on. Although, in the British climate, the main supply-pipes seldom freeze, the small tubes and valve sometimes give trouble from this cause in an extreme winter. The rubber tubing used for the exhaust water, if not kept in good order, will cause a nuisance by leakage. Portable machines of this kind have been found effective not only in boiler-making, and in



232.
Portable hydraulic riveter.

Transmission of power in flexible tubes.

Cost of portable riveters.

Accessory cranes.
See Chap. XXVII.

Riveting *in situ.* bridge factories or ship-building yards, but for riveting *in situ* during the erection of large bridges, as for instance at the Forth Bridge, where riveting was done 400 ft. above the level of the motor. In cities where hydraulic power mains are established, riveting can be effectually and silently performed without any contiguous motor, as for instance the riveting of the girders when Charing Cross Bridge was widened, the pumping motor being a mile distant.

Compressed-air riveters. *Compressed air* is sometimes employed as the medium of power for portable riveting-machines, the apparatus, in regard to portability and shape, much resembling the hydraulic riveter. The pressure is only about one-tenth that usual in hydraulic machines, but the same effect on the rivet-closer is obtained by a larger cylinder and longer toggle lever. A complete apparatus, including an air-compressing **Compared with hydraulic machines.** steam-engine, costs about £250. The machine is rather heavier than a hydraulic machine, but it is free from the inconvenience of freezing and leakage above referred to. It may be said that for rivets up to ¾-in. diameter, and 2 in. long, the two systems offer about equal facilities; the hydraulic machines being more effective **See ROCK-DRILLS, page 816.** for heavier work. By another pneumatic plan a rapid succession of blows, each of only moderate force, is given as in a rock-drill, with a result like that in hand-riveting.

Choice of machine tools, how determined. Referring to the various operations described in the preceding pages, *the Choice of machine tools* is greatly assisted by a plan of the workshop showing the position the machines are to occupy and the space available for them; an elevation and cross-section showing the driving shafts, their distance from the wall and roof (thus indicating the length of belts and clearance-space for pulleys); the thickness of the wall or roof-beams available for supporting overhead gear; and information as to the diameter and speed of the shafting which is to **Transmission of power. See page 504.** drive the machine. The alternative of electric transmission should be considered, and if an electric-lighting plant or a supply of electric current is established or available, the maker of the machine tools can have the opportunity of arranging for dynamo motors. In England, machine tools are generally fixed upon stone beds, but **Foundations.** timber is sometimes employed. Stone is preferable to timber, but as concrete will serve equally well, it is easier and cheaper to export Portland cement to countries where indigenous stone is wanting, if suitable gravel, ballast, or other material for making the concrete be obtainable in the locality.

Solid beds for machines.

Adjustment of supports.

The importance of fixing a machine exactly level on a solid foundation cannot be overstated, for the correctness of its work is imperilled by an uneven or yielding bed. Inequalities in a stone or concrete bed may be adjusted by grouting the joints. If the supports are not in a true plane, the machine, especially if it covers a large area, may, in settling down to the place provided for it, become distorted or strained. Indeed some engineers consider it so difficult to adjust exactly four bearing places, that they prefer to make only three of the supports rigid, which can be arranged without difficulty, and to make the fourth jointed or otherwise adjustable to allow of exact setting.

Repetition work.

Special machines where applicable.

A full knowledge of the purpose for which the machine-tool is intended greatly assists a proper choice, for there are many alternative arrangements of detail from which can then be selected the one suited for the case in view. Moreover, if a constant repetition of similar work is intended, special self-acting or automatic arrangements can be provided to increase the service and to cheapen the cost of working. On the other hand, special machines, which may be useful in large factories are out of place when the work is of miscellaneous kind or is limited in amount. Summarising the suggestions conveyed in the preceding pages for particular tools, it may be stated generally in regard to all, that, to allow of a proper selection of the machine needed, the following information should be furnished by the purchaser:—

Purpose of machine.

1. A description of the *Trade* for which the tool is needed.

Size and weight of work to be done.

2. The *Size and weight of the pieces* or articles to be operated on. This may either be given by approximate dimensions and weight, or may be sufficiently indicated by a description of the commodities to be manufactured. Thus, in the case of locomotive, marine, or stationary engines, their size or horse power will convey a good idea of the capacity of the machine tools necessary. So if ship-building be the trade, the size and kind of vessel built will tell approximately the strength and size of the various tools.

Competitive designs.

See page 421.

In purchasing machine tools, it may be sufficient to furnish the foregoing particulars to the manufacturer, on whom will then rest the responsibility of supplying what is suitable. If competitive offers have to be considered, a specification and drawing from each maker will be required in order to allow a comparison of values. To facilitate such comparison and to narrow the differences of various designs, certain main features may be prescribed by the purchaser. Dimensions of length, width and height may be stated, as well as the scope of the machine in regard to the size of the article to be treated. But such particulars are not conclusive unless the speed and capacity be also stated, as the framework, while large enough for the desired purpose, may not be so strong as another for cutting or piercing at a profitable speed the metals dealt with. The specification, whether of buyer or seller, should enumerate the accessories or duplicate parts that are to be supplied. It is usual for the machine tool maker to include in the price the brackets, pulleys and other driving apparatus for transmitting and regulating the power from the main shaft of the factory, but as such a condition may admit of different interpretations, the various appurtenances should in each case be described. So also the driving-belts, cutting-tools, tool-holders, spanners, holding-down bolts, and other minor parts should be enumerated.

Accessories and duplicates. *See page 452.*

Machine tools generally pack closely for shipment, the weight usually exceeding the measurement tonnage. Large or long pieces require special protection against damage, and all small parts have to be packed in close cases. The cost of packing for shipment ranges generally from 3 to 5 per cent. on the purchase prices.

Packing for export. *See page 447.*

Testing-machines.

Testing-machines for measuring the strength and other qualities of engineering materials are made of varying capacities ranging from small simple machines to measure a 500-lb. pull upon specimens of a few inches in length up to large combined machines to measure stresses of 500 tons, either by pulling, pressing, bending, or twisting, upon pieces of considerable length. The smallest machines are for testing samples of such materials as cement, wire, hoop-iron or cast-iron bars. For testing samples of steel and iron, 50-ton machines are generally used. Machines of a larger size are more suitable for testing actual members of construction, such as bricks under pressure, which demand 100 tons of power, chain-cables, which may require 250 tons power and a capacity in length of 90 ft.; and machines for testing the ties and struts of bridges, or for testing cast-iron columns in compression or beams in deflection. The most powerful testing machines hitherto made are available up to 500 tons tension, and take in lengths of 30 feet.

Purpose and capacity.

50-ton machines usual.

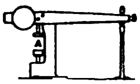
Large machines.

The most valuable and trustworthy machines are those in which the stresses are measured by dead weights rather than by springs or gauges. In all the best modern testing-machines the forces necessary to elongate, compress or bend are applied by straining gear to

Stress, how measured.

one end of the test piece, and the balance for measuring the force is applied to the opposite end of the piece.

Hydraulic power.



223.

Range of power.

Fig. 223 shows a good type of machine for testing sample pieces of iron and steel. The force is given from a hydraulic cylinder. The amount of stress which passes through the sample fixed in the gap, A, is measured by the self-balanced steel-yard, S. Machines of this particular type are made of such powers as 50 and 100 tons, and will measure accurately to 3 lbs. Such a 100-ton machine would be useful for testing anything from fine wire up to bars of steel 2 in. in diameter, and, if fitted with compression apparatus, can be used also to test the crushing strength of a brick or the stiffness of a short strut.

Horizontal machines.

Choice, how determined.

Such machines are well suited to take in lengths up to 5 ft., but for greater lengths a horizontal machine is more suitable, especially since an arrangement of the latter type has been perfected, in which, without the slightest delay in changing the clips and other accessories, a piece may be tested and broken either by pulling, pressing, bending, or twisting. The proper choice of a testing-machine depends on:—

Power.

1. the *Power* required, which commonly lies between 5 tons and 500 tons.

Length of capacity.

2. The capacity of *Length*, commonly varying between 10 inches—which is the length between Board of Trade gauge-points for samples of boiler plate—and 90 feet, which is a Board of Trade length of chain cable.

Variety of stresses.

3. The number of *Directions* in which the strains may be applied, whether in pulling only, or in pulling or pressing; whether for bending only, or for pulling, pressing and bending; whether for twisting only, or for twisting in conjunction with all the other directions.

Torsion.

Combined machines.

The twisting apparatus in combined machines is not usually made to the full capacity of the machine for testing in other directions, but generally to twist up to about 1 in. diameter in a 50-ton machine, 2 in. diameter in a 100-ton machine, and 3 in. diameter in a 250-ton machine. Separate machines are made for each separate direction of straining, if so required, but the largest and most combined machines are just as effective and trustworthy for small tests, and in all the different directions, as are the small separate machines.

Cost of testing-machines.

The *Cost* of a testing-machine must obviously vary according to the above points, namely, *Power*, *Capacity*, and the number of *Directions* in which it can be used. Besides this, the cost of a testing plant, may be enhanced by the provision of a separate accumulator and pumps for working it, and possibly by an engine and shafting for driving the pumps. As a broad average between the simplest and shortest, and the most combined and extensive machines, a cost of £10 per ton of balancing power gives the approximate cost of a good machine, exclusive of motive force: that is to say, where existing pressure water is available for the hydraulic cylinder, or power shafting for driving the straining gear.

Management of machine tools.

The proper *Management* of machine tools is one of the most important conditions in the profitable carrying on of an engineering factory. In regard to the machines which have been enumerated in the preceding pages, it is obviously important to utilise them to the utmost by having the most perfect cutting-tools and by keeping them fully employed; but too often, even when care and money have been expended without stint on the machines, the results are inadequate for want of attention to these conditions. Assuming that the machine has been well chosen in regard to the work to be performed, the amount of service depends mainly on the following points:—

Readiness for work.

(*a*) The *Readiness* with which the article can be attached to the machine and adjusted, more time being often expended in this than in the actual working of the tool. Much invention has been directed to these operations, and the less variety there is in the size and shape of articles, and in the kind of service required, the more scope will there be for improvements and for the application of "special" tools.

Shape of cutting-tools.

(*b*) The shape of the *Cutting-tool* and the manner in which it is held. Skilled workmen acquire great aptitude in the shaping of tools to the proper form, and in their ready application to the purpose in view, but they are greatly assisted by having steel of appropriate shape from which the tools can be fashioned, well-contrived grindstones or emery-wheel grinders, and tool-holders which allow quick adjustment.

Grinding.

See Emery-wheels, *page* 755.

Quality of tool steel.

(*c*) The operation of a cutting-tool and its endurance obviously depend much on *the Quality of the Steel* and on its suitability to the metal it is to cut, though this consideration does not always receive the attention it deserves. The better the steel, the longer it will work before needing to be re-shaped or re-ground; and by a careful choice of the kind of steel, the maximum speed of the cutting-tool can be obtained, there being wide limits within which economy in this respect may be promoted.

(*d*) The *cutting Speed* of machine tools, as well as the depth and width of cut, should be carefully studied by those who have the management of workshops. In many cases, even where attention is paid to other points, these are left to the discretion or whim of the individual workman, while it should be obvious that on them the profit or loss which will result from a given outlay in machinery, wages and current expenses very largely depends. The amount of work which machines of similar kind and capacity will produce varies in even first-class factories as much as 50 per cent. The necessity and the advantage, both to employer and workman, of payment by results are ever becoming more evident, but the scale of payment for piece-work can only be equitably arranged on some standard basis in these respects. The area of surface finished in a given time, or the number of holes punched or drilled, should be tabulated for each of the metals dealt with, and some standard set up. Even then the best results can only be obtained by a wise expenditure, in the first instance, on true, powerful and rigid machines that can be worked at a maximum speed. Not only has the power of the machine to be suitable for the speed, width and depth of cutting, but the article operated on must be strong enough to resist the pressure of the tool.

Speed of cutting-tools.

As basis for piece-work.

Power and rigidity.

(*e*) Even with the best machines and cutting-tools, the cost of working depends greatly on the *Organisation* of the workshop and the order of procedure. In many cases, one skilled workman, assisted perhaps by a boy or labourer, can manage two or more machines; and although such an arrangement is often opposed by the fallacious reasoning of trade-unions, it is obvious that the workman who can so utilise the machinery enhances the value of his services. Where-ever possible, relays of tools should be in readiness to replace those which are worn or broken; and in many factories, the workmen who control the machines are not allowed either to shape or grind their own tools, as not only their own time but the valuable time of the machine is lost while they are absent from it. In well-managed factories, store-rooms are provided for loose tools, which are kept in good order and issued to the workmen in a systematised manner.

Organisation of workshops.

Relay tools.

Tool stores.

(*f*) *A Clean, well-ordered Workshop* has much to do with the good condition of machine-tools. A floor of wood blocks, or asphalt, or other substance which gives out little dust, is an advantage. The wearing parts of the machines should be preserved as much as possible from dirt and grit, and oil of good quality only used. Under

Clean workshops.

Lubricating oil.

favourable conditions in these respects, the workmen will be found to take care and pride in keeping their machines in good order; and even some degree of smartness—such as the polishing of bright surfaces—may be encouraged, because such attention generally brings with it care to the more essential parts of the machine.

Wear and tear.

(*g*) The "*Wear and tear*" of machine tools has to be considered in estimating the cost of work done; and, notwithstanding maintenance by repairs, the book value of the machines should be regularly reduced to correspond with the deterioration taking place. For while, in the financial administration of a factory, the accounts which relate to disbursements and receipts are so obviously necessary to the continuous working of the undertaking as to be rarely neglected, the capital accounts are not always deemed to be of such pressing importance; and variations in the value of plant arising from the wear and tear are often left unnoted. The temptation to treat as profit the surplus of income over expenditure, without sufficient allowance for deterioration, appears to be often irresistible. No fixed rules or rates of depreciation can be established for general use, because not only do trades and processes of manufacture differ, but numerous secondary circumstances have to be considered in determining the proper course. There are, however, general principles which ought always to apply, and every manufacturer can by proper investigation of his accounts arrive at suitable rates.

Depreciation.
See page following Index.

Principle of "writing off."

[*See also* THE ESTABLISHMENT OF FACTORIES: THE TRANSMISSION OF POWER: *and* SMITHY TOOLS.]

CHAPTER XXVI.

SMITHY TOOLS AND STEAM-HAMMERS.

Well-arranged smithy.

A WELL-arranged and well-kept smithy is generally evidence of good management in an engineering factory; but very often, even where skill and money have been expended on the other departments, the arrangements of the smithy are rude and defective. Smiths' hearths are generally arranged along the wall, and the anvil, steam-hammers, and other machines in the centre of the smithy. This plan economises space; one line of blast-pipe will serve all the fires; and cranes, if needed as adjuncts to the hearths, can be conveniently attached to the wall. The hearths may be placed either singly or in pairs, or sometimes even in groups of three or four; these arrangements and the distance between the hearths depending mainly on the dimensions of the forgings to be made. The smoke and fumes from the hearths may be conducted either by bend-pipes from the hoods to chimneys constructed in the wall, or vertically by light iron chimneys through the roof. Where hearths are arranged in pairs, the two hearths are sometimes covered by one hood; but this plan, though effective, requires a hood of large size, inconvenient to make and carry. It is sometimes found convenient to conduct the smoke from numerous hearths to one chimney, through a horizontal tube of large diameter, with which the hoods of all the hearths are connected. A smithy should be lofty and well ventilated; the floor should be made of iron borings, wood-blocks or other compact substance, kept clean and watered; and there should be an abundant supply of water conveniently placed; the comfort and efficiency of the workmen being much promoted by such arrangements.

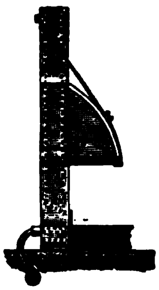
Hearths placed singly or grouped.

Smoke pipes and hoods.

Ventilation.

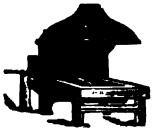
Smiths' hearths may be broadly classed as of brick and iron.

Brick hearths are preferred by some engineers: they are easily built, and in a foreign country where good bricks are made require



224.
Brick hearths.

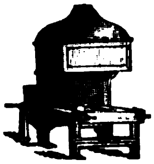
the minimum of imported material. A cast-iron back-plate, tuyere and water-cistern, cost from £4 to £8, according to the size of the hearth; and the rest of the structure may be made of brick. To ensure a proper upward draught, a hood is generally necessary to conduct the smoke and gas fumes to the chimney; and the hood, if of brick, is conveniently supported on an angle-iron frame, held back to the wall or chimney by tie-rods. Brickwork is preferred sometimes because less heat radiates from it into the smithy than from iron, but the same advantage is obtained in an iron hearth by lining it with fire-brick. In some cases the hood is made of brickwork for its supposed coolness, while the base and fire-pan of the hearth are made of iron. The ironwork for such a hearth costs little less than a hearth entirely of iron. It is sometimes sought to avoid hoods altogether, and hearths so arranged are found to work well in some factories. But this plan is only possible by a special system of ventilation, a vertical draught sufficient to carry the smoke to outlets in the roof being ensured by doors or other air inlets in the side walls.



225.
Iron hearths.

Iron hearths are generally preferred to brick hearths in modern engineering factories, as they are self-contained, occupy less room, can be purchased ready-made, and are cleaner in use. They are generally made of cast iron, except where the risks of breakage in long or difficult land-carriage render wrought iron safer. Cast-iron hearths, as suitable for ordinary engineering smithies, weigh from 10 to 22 cwt., and cost from £10 to £25. Hearths of particular shape and size are made for many of the special purposes in an engineering factory. For large forgings, circular hearths standing clear of the wall, and with a converging blast from three tuyeres, are often employed. Such a hearth, for instance, is used for heating railway wheel-centres. For small forgings, such as for carriage ironwork, small-arms making, and other special repetition-work, small hearths of appropriate shape are contrived; and they are often entirely enclosed instead of with open sides as usual for ordinary smithing. Sometimes the hood is raised, and its lower part lined with fire-brick set in fire-clay. Fire-bricks of ordinary size and kind may be used; such bricks cost about 1*d.* each, and are exported in considerable quantities, but they are occasionally made of special shape and size to fit the hearths. For out-of-door work, smiths' hearths are sometimes made without a hood; but it is then generally found necessary to provide a screen as a shelter from the wind.

Converging blast.



226.
Enclosed hearths.

227.

The fire-plate of a hearth is often made of special size and shape to suit particular work. For certain rough or heavy forgings—such for instance as anchors and chain-cables—a hearth-plate stronger than usual is necessary.

Bellows.

Various improvements have been effected in smiths' hearths, especially in the mode of producing the blast, and in the tuyere or nozzle by which the blast is admitted to the fire. The hand-bellows produces a blast slowly and laboriously, and for large forgings is inadequate. It has long been superseded by rotary fans or blowers wherever power is available for working them, and even where mechanical power is not obtainable hand-machines are often preferred to bellows.

Revolving fan.

The *Fan* in some respects resembles the centrifugal pump, for it is circular, is armed with radial blades and revolves inside a case. The fan blast is, however, limited to a pressure equal to that of a column of water about six inches high; and to raise a blast sufficient for a smith's fire a high speed is necessary, from 1200 to 1500 revolutions per minute being ordinary rates. A fan sufficient for supplying 7 fires with blast costs about £8; while one for 15 fires costs about £16. To these prices must be added the cost of the shafting, pulleys and belts between the motor and the fan which are required to multiply the speed, and which absorb much power.

Blower.

Limits of blast pressure.
See also page 503.

The *Blower*, which was invented long after the fan, is, in the opinion of most engineers who have tried it, a more effective machine. It has a rotary motion, but it revolves at about one-fifth of the speed; it works in a close-fitting case, and forces the air steadily before it, instead of, like a fan, merely beating the air. A blower is more costly than a fan, but requires fewer shafts, pulleys and belts, and less power is necessary to produce a given blast. A pressure of 2 lbs. to the inch can be obtained from a blower, and it is convenient to have such a force available, even though it be checked and reduced in the hearths engaged on light work. There are some cases where even a higher pressure is useful for concentrating a fierce heat on some special forging or welding surface. When a blowing-engine is already established, as, for instance, for a cold-blast smelting furnace, the current of from 2 lbs. to 3 lbs. pressure may, if suitably controlled, be used for foundry melting, cupolas and smiths' hearths.

Air-blast conducted in pipes.

The blast from a fan or blower can be conducted a considerable distance in pipes, which are generally laid about one foot below the ground or floor of the smithy. Sometimes wood or brick conduits, or earthenware pipes, are used; but iron pipes are generally preferred, as they are tighter against leakage, are less liable to fracture, and there is less surface friction. The air pressure is so slight that sheet-iron pipes are strong enough, though they are less durable than cast-iron against rust; the choice depending upon which is more easily obtained in the locality.

Stand-pipe.

Water-tuyere.

Vertical tuyere.

By the side of the smiths' hearth, a stand-pipe with simple shutter-valve or plug-valve conducts the blast from the underground pipe to the nozzle which enters the hearth. As the blast has to be conducted into the heart of the fire, the nozzle is liable to be burnt away by the intense heat, and to preserve it as much as possible the water-tuyere is generally used. This tuyere is a double pipe of cast iron passing through a cistern behind the hearth, and the annular space being thus kept full of water, the effect of the fire on the nozzle is thus greatly reduced. Water-tuyeres are bulky, necessitate a cistern of water, and are not always used even in fixed hearths, and hardly ever in portable forges. One plan of supplying air without the water-tuyere, is to bring the blast from below by a vertical pipe into the centre of the hearth through a small perforated plug or plate, which fits into the mouth of the pipe. Such a plate is not so much exposed to the intense heat of the fire as a nozzle which projects horizontally, and it can be cheaply replaced when burnt. The fire-pan of a hearth so supplied with air can be made shallower than that of an ordinary water-tuyere hearth; but although many smiths who have used them prefer the vertical blast, the horizontal water-tuyere is still used in the majority of cases. The plan of a central tuyere has been elaborated by making the plug to move upwards, so that it not only serves to regulate the blast, but, when so moved, to clear the fire.

228.

Closed furnaces.

For heating plates or wheel-tires.

Closed furnaces are used for many of the processes in an engineering smithy, for which a smith's or open hearth, which concentrates an intense heat on one lump of iron, or on one portion of a large piece, would be quite unsuitable. When large surfaces have to be brought to an equable heat—as in the case of wheel-tires or the slabs from which iron plates are to be rolled—an enclosed furnace without a force blast is used, the necessary draught being provided by a suitable arrangement of the flues and chimney. If coal or coke is used, the article to be heated is not brought into contact with the hot fuel, but the heat, generated in one corner of the furnace on ordinary fire-bars, passes through and around the chamber to be heated. But coal

Producer-gas. *See page* 481.

Water-gas.

Furnaces lined with fire-brick.

Ironwork for furnaces.

Forced draught.

or coke fuel has been largely superseded by producer-gas in engineering works, and gas applied in regenerative furnaces is almost exclusively used in the more important metallurgical operations of an iron or steel works. Producer-gas is made on the premises at a cost of from 1*d.* to 2*d.* per 1000 ft., including interest on the capital cost of the plant employed in making it. Water-gas (made by passing steam over incandescent coke and so decomposing the water) has some advantages over producer-gas in its freedom from certain impurities, and may be mixed with it where steel has to be heated for welding. The use of gaseous fuel for these and other purposes is likely to extend. Furnaces, whether for coke or gas, are built of brickwork, with a lining of fire-brick, are encased in iron and held together by outside tie-rods against the heat-expansion, which would otherwise crack or break them. The brickwork may with advantage be entirely of fire-bricks jointed with fire-clay, but often a lining of fire-bricks is built within ordinary bricks. Roughly-made cast-iron plates may be used as the outer casing. Wrought iron is sometimes preferred as being less fragile; but if cast-iron plates become broken, as is almost sure to happen eventually, they are still serviceable, if there be sufficient connections and bolts. The ironwork for furnaces as just described, of the kind used in a locomotive factory or general engineering works for such purposes as tempering steel springs, heating wheel-tires and centres, or for heating scrap-iron for hammering, weighs from 8 to 20 tons, and costs from £80 to £150 according to the size and purpose required. Larger furnaces are needed for heating large masses of iron in those factories where powerful steam hammers are employed. Small brickwork furnaces, in which the fire is stimulated by a forced draught, are used instead of forges for heating rivets in a bridge or boiler factory, where, as for a riveting-machine, many rivets have to be supplied quickly.

Smithy tools.

Cranes. *See page* 791.

Anvils.

Cranes, anvils, swage-blocks, swages, fullers and hammers, are the most important of the many miscellaneous tools used in a smithy. Light wrought-iron *Cranes* attached to the walls or to the side of a furnace, for lifting forgings from the fire to the anvil, cost from about £12 for one lifting 5 cwt., to about £20 for one lifting 20 cwt.; while for lifting heavy forgings to and from a steam-hammer, more powerful and expensive cranes are required. *Anvils* for small forgings weigh from 2 to 3 cwt., and cost about £5, but for an ordinary engineer's smithy the anvils weigh about 4 cwt., and cost about £8. Anvils are frequently fixed upon a block of timber, Swage-blocks.

which absorbs and softens the concussion, and sometimes on cast-iron stands weighing 2 to 3 cwt., costing from £1 to £2. *Swage-blocks* are made of cast iron, are generally rectangular, are perforated with variously-shaped holes, and have grooves on the sides by which the smith is assisted in hammering, shaping and twisting the iron he is forging; and the blocks serve also to hold loose swages or dies. These blocks weigh from 2 to 6 cwt., they may be supported on a wooden block, or on a cast-iron stool like an anvil block, and they cost from £2 to £4.

Hammers.

Small tools.

Among the loose tools in a smithy, iron *Hammers* with steel faces cost about 7*d.* per lb., and steel about 12*d.* per lb. *Swages* are made of wrought iron or steel, and are made convex or concave in a variety of shapes. These, as well as the tongs and cutting-sets, a good smith will often prefer to make for himself; but in establishing a new factory—especially in a foreign country where there are not smiths skilled enough to make such tools—it is usual to purchase them. Iron tools cost about 6*d.* per lb.; steel tools 12*d.* per lb.; and those of iron and steel combined, 9*d.* per lb.

Portable forges.

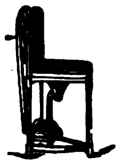
With bellows.

Deck forges.

Fan blast for portable forges.

Blowers. *See page* 773.

Portable forges are made in various ways, and in all it is endeavoured to obtain the maximum capacity with the smallest weight and size. The majority of small forges have leathern bellows—square or round, according to the shape of the forge—worked by a hand-lever or by a foot-treadle. The bellows is generally made double-acting, so as to emit a blast during both the up and down movements, the current of air to the fire being thus almost continuous. Light sheet-iron forges thus equipped with bellows cost from £5 to £8. They are known as "deck or riveting-forges," and are generally used by ship-builders, bridge-makers, boiler-makers and gas-holder makers, for heating rivets, and they can easily be carried from place to place. Such forges, as generally made, are cheap and fragile, and do not last long. As the bellows affords only a small blast, attempts have been made in various ways to apply the fan or blower. As it is essential that a fan shall revolve at a high speed, quickly-running belts, pitch-chains, or toothed wheels are necessary, which, inconvenient at all times, are especially unsuitable and liable to damage in a portable forge. The blower has, however, been successfully applied, and forges so equipped form permanent and efficient tools, suitable not only for heating rivets, but for ordinary smith's work in factories where forgings of moderate size and thickness are made, or on public works where there is no blast from a fixed blower available.



229.

Strong forges of iron.

Military forges.

These forges are serviceable in the engine-rooms of steam-ships, for workshops on upper floors, and in all places where a large or brick-built hearth is inconvenient. The forges are made either of cast iron, or of a combination of cast, malleable-cast, and wrought iron, and the best of them are ingeniously contrived so as to allow, in a small space, forgings of considerable size to be brought to welding heat in a short time. The forges range in price from £8 to £16, and weigh from 1 to 6 cwt., the larger size being capable of producing a welding heat in a bar 2½ in. diameter in five minutes. In remote places, where occasionally forgings beyond the capacity of a portable forge have to be made, a temporary brick hearth can be built, a blower complete with hand-gear being alone imported. For the military train of an army, portable forges are specially made to resist fracture, and to fold up into small space for carriage on the pack-saddle or baggage-wagon.

Steam-hammers.

Steam-hammers are conspicuous among the numerous inventions, the outcome of the steam-engine, by which the ruder operations of the workman are performed by mechanical force.

Tilt hammer for iron blooms.

Limited power.

Oliver hammer for rivets and bolts.

Various mechanical contrivances for aiding or cheapening the forging of iron were in use long before the introduction of steam-hammers, but such contrivances were unsuitable for miscellaneous smiths' works. In the process of iron-making, various kinds of tilt or cam hammers, worked by steam or water power, were devised for compressing and hammering the "blooms" of iron before they were rolled into bars or plates. The power was applied to the lifting or tilting the hammer or tup, the useful work being performed by the falling weight, but the fall seldom exceeded 15 inches, and only about fifty blows at most could be given per minute. Moreover, no adjusting or regulating of the blows was possible, and it was difficult to apply such hammers to any but simple processes of an accustomed kind. For small repetition work, such as the making of bolts, spikes, nails or rivets, small tilt hammers of various sorts were in use a hundred years ago; and, with slight modification, and now sometimes known as an "oliver," the same kind of machine is still employed by the numerous craftsmen and home workers in the hardware districts; and in particular trades there are often minor operations in a smithy where tools of this kind may be employed with advantage if steam is not readily obtainable, especially if power-shafting or water power is available for working the tools.

But while such mechanical contrivances have long been available for such simple forms of forging and welding, they could seldom be applied in the smithy of an engineering factory, where, before the invention of the steam hammer, the only means of forging iron in large or heavy pieces was to increase the number of men wielding striking-hammers. From two to six men would be employed, so as, by striking in turn, to give a continuous succession of blows. Strong and skilful as these workmen became, they could at most only wield hammers of about 20 lbs. each, and the blows fell with feeble effect on the masses of iron with which they dealt. Where such were the only means available, the iron had to be heated several times; the outlay for fuel was therefore great; the strikers were idle between the heats; welding of large or heavy pieces was imperfectly performed; and as the size of forgings was limited by the force available, cast iron or timber had often to be employed in structures or machinery, where forged wrought iron would have been preferable.

Manual striking-hammer.

Limits of weight.

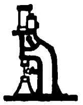
Nasmyth steam-hammer.

The first steam-hammers by Nasmyth were single-acting, that is to say, the steam was employed only to lift the tup; but heavier hammers and quicker blows were at once rendered possible. The special and novel feature in these was the valve, by which the workman could, by admitting steam below the piston, arrest the falling weight at any desired distance from the anvil, and, by interposing what is in effect a cushion of steam, make the blow thus shortened at will also light or elastic. The single-acting hammer was soon improved by admitting steam above the piston, thus adding immensely to the force of the blow; the power in this respect being indeed only limited by exigencies of transport, which determine the size and weight of the framing, and by the stability which can be given to the anvil and its foundations. These double-acting hammers at once revolutionised the art of forging, increased the size of blooms and slabs, and consequently of bars and plates in the rolling-mill, cheapened heavy smiths' work, and rendered possible the manufacture of the enormous engine-shafts, rudder-frames, armour-plates and other articles, where large masses of steel or wrought iron have to be dealt with. Single-acting hammers are quite obsolete in most engineering factories, but they are still preferred in some cases for use as large-size heavy forge hammers, when rapid striking is not required. They are less liable than double-acting hammers to break down.

Single-acting hammer.

Double-acting hammer.

The single-frame hammer is the most convenient for smith's work, as it affords the maximum space within which the forging may be



230.

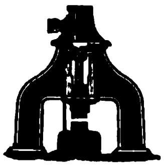
Single-frame hammer.

moved. The workman can stand either in front or at the side, as the shape of the forging or the nature of the work requires, the regulating handles being accessible from either position. The greater the distance, A, the more space is there for the articles dealt with, and a blow can be struck or a welding effected at a greater distance from the edge of the article; this being occasionally a great advantage. But it is obvious that the overhanging cylinder imposes severe strains on the framework or standard of the machine, which in this respect may be compared to a punching or drilling machine, where any increase in the depth of gap rapidly increases the strains on the framework. Hammers of this type suitable for moderate-sized forgings, are rated at from ½ cwt. to 10 cwt.; have cylinders ranging from 4 in. to 12 in. diameter; weigh from 1 to 8 tons (including anvil-blocks); and cost from £50 to £200. They are occasionally made with cylinders as large as 15 in. diameter, and are rated to 20 cwt.: they then weigh up to 17 tons, and cost about £300; but beyond the usual limit of 12 in., the single standard or support, to be of sufficient strength, is cumbrous and inconvenient, and the double support becomes necessary.

Depth of gap.

See page 757.

Sizes and prices of hammers.



231.

Double-frame hammers.

It will be seen that the double form of machine affords a greatly increased capacity, and, as already stated, the limit of size is determined by such circumstances as the stability of foundations to receive the shock, and the carriage of heavy pieces from the manufactory, rather than by any difficulty in making the hammer itself sufficiently strong. But the cost of such machines increases rapidly with the size, and especially with the width, which, however, may be often advantageously made large at extra expense. Hammers of this kind are seldom made with cylinders of less than 10 in. diameter, with a rating of 7 cwt., a machine of such a size weighing about 6 tons including anvil-block, and costing about £150. In an engineer's factory, a hammer with a 15-in. cylinder, rated at 20 cwt., costing about £300, is seldom exceeded; and if, to save carriage to a foreign country, the anvil-block or base-plate be omitted, the price would be about £200. Occasionally 50-cwt. hammers are used for making large crank-axles, although in many cases where large forgings are only occasionally wanted, it is better, instead of attempting to make them, to purchase them from those who confine themselves to the manufacture of heavy forgings. It is in iron or steel works that the larger steam-hammers are needed. For shingling iron blooms, a process preparatory to that of the rolling-mill,

Usual sizes.

See page 476.

For iron and steel-making.

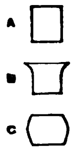
Weight and price of hammers.

Hammers superseded by presses. *See page* 785.

hammers with cylinders of about 19 in. and rated at not less than 50 cwt. are usual, such a hammer costing about £600; while for hammering steel ingots into blooms of a size usual in an English steel-rail factory, a 100 cwt. hammer, with a cylinder not less than 28 in., would be required, costing about £1200, or £500 less if the anvil-block or base-plate be omitted. From this size upwards, hammers are generally made specially for the purpose in view, the heaviest being those used in the manufacture of armour-plates and big guns. Some of these hammers are rated at 80 tons, and cost, with anvil, boilers and other appurtenances, £6000 and upwards. In some notable cases heavy bed-plates have been cast *in situ* or in a contiguous melting furnace, from which they have been propelled on rollers to their position. In some iron and steel works hammering is almost entirely avoided, steel ingots and iron blooms being reduced by rolling through revolving squeezers or cogging mills, or by squeezing or cogging in powerful hydraulic presses. Some engineers, however, still prefer iron or steel which has been hammered.

Rating of hammers.

Steam-hammers have been generally rated according to the weight of the falling tup, including that of the piston and rod, which of course add to the effect; but it is obvious that the mere dead weight of the falling parts gives an entirely inadequate idea of the force of the blow, which depends, not only on the velocity arising from the depth of the fall, but, in double-acting hammers, on the steam-pressure on the piston. There is no established standard or measure by which to rate the real force or effect of a steam-hammer, and it is difficult to express the force of a blow in terms of foot-lbs., because the effect of velocity on different weights of hammers has different effects. The *energy* of a 14-lb. sledge or manual striking-hammer moving at the rate of 15 ft. per second is approximately equal to 50 foot-lbs. A 1-lb. hammer moving at the rate of 56 ft. per second would have the same energy stored up in it, but the impact or effect on a piece of hot iron would not be the same, nor would a repetition of blows from the lighter hammer produce the same effect.



232.

See PILE-DRIVERS, *page* 847.

Light blows take effect only on the part immediately presented to them, while a heavy blow is felt by the mass. Thus, if a forging, A, be presented to a light hammer, the effect will be as at B, while if struck by a heavy hammer the effect will be as at C. In this respect the difference between hand and machine-riveting, or between manual and machine pile-driving, afford analogous cases.

There are four kinds of blows which can be given by a double-acting steam-hammer; (*a*) the single-acting blow by which the steam is only admitted for the upward stroke, the work being performed by the falling weight; (*b*) the above method controlled or cushioned by the admission of steam below the piston as it falls; (*c*) the pressure-blow with steam above the piston, but cushioned as in the second method; and (*d*) the "dead blow," by which the full pressure of the steam is applied above the piston during the whole stroke, and also after the tup has fallen, so that it not only descends with its greatest force, but remains as a squeezer on the forging. The action of the hammer in these respects is entirely controlled by the valve-lever, and by one man, who soon becomes able to regulate the blows with greatest nicety to the purpose in view. In the largest machines the workman stands on a small platform affixed to the side of the framing, and in smaller machines on the floor of the smithy. In all but the smaller-sized hammers, there is a driver who works the valve-lever of the machine, under the orders of the hammer-man, who guides and controls the forging. But in the smaller machines and steam-stamps the hammer-man is himself able, by a treadle-lever, to work the valve with his foot. Such a method, which economises the cost of labour, is commonly adopted for light forgings, such as files, cutlery and bolts. A velocity at the moment of striking of from 20 ft. to 27 ft. per second is generally found most effective on a steam-hammer. The number of blows per minute ranges from 40 per minute with the largest hammer and the heaviest forgings, to 300 and 400 per minute in hammers and stamps of small size.

Steam-hammers give four kinds of blows.

Hammer blows, how controlled.

Speed of falling tup.

The concussion to which a steam-hammer is subjected tends in time to loosen the parts, and when once they are out of true line, they will break if further work is attempted. To resist these loosening strains, the cylinder and piston-guides must be strongly and exactly fitted, and it is very important that the bed-plate be massive and well fitted upon the foundation; and in large hammers, where it is necessary to make the bed-plate in several pieces, they should be so closely fitted and held together by bolts or keys that they cannot be shaken loose. The standards or framing should be accurately fixed upon the bed-plate, and the cylinder and piston-guides placed exactly perpendicular, and attached in the closest and tightest manner. Standards of riveted steel are sometimes made, but though they are easy to construct and are light for carriage, the vibration tends to loosen the rivets. The piston-rod becomes

Concussion loosens hammer framing.

Massive bed-plate necessary.

Accurate fitting.

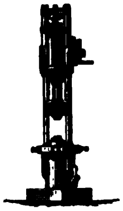
crystallised by constant percussion, and has periodically to be renewed. The piston-rod is best made of high-quality wrought iron.

Manufacture of steam-hammers a specialty.

Since the main principles of the single and double-acting hammers were adopted, the manufacture of such machines has become a specialty, and a great variety of shapes and sizes have been devised for special trades and purposes. The shape or kind of steam-hammer is determined by the purpose to which it is to be applied; first, in regard to the weight or mass of iron to be dealt with—the strength of the framing and area of the piston being so decided; secondly, by the form and dimensions of the forgings, which render a certain shape of machine preferable or necessary. Where the hammer is to be applied to articles of a repetition kind, as is often the case in special trades, the machine may be made to accord very exactly with its work; but where, as in an engineer's factory, miscellaneous articles have to be forged, then, in order to admit them, more latitude must be left in regard to the shape, size and situation of the machine.

Shapes and sizes, how determined.

Stamp-hammers of a special kind are used for forging small articles in dies, and are mostly used for repetition work. These stamps are compact in shape, have cylinders ranging in size from 5 in. to 15 in., and cost from £60 to £300.



233.
Stamp-hammers.

Steam consumption.

The *Steam consumption* of a steam-hammer depends mainly, as in a steam-engine, on the diameter and stroke of piston, the degree of expansion or cut-off adopted, and the average number of strokes per minute. But there is also to be considered the length of time occupied with one heat of the forging, for a great force may have to be concentrated into that period.

Store of steam for concentrated hammering.

Assuming that the hammer is actually working for ten minutes in each hour, the number of strokes in that time would afford a measure of the quantity of steam required; where, however, it is important to concentrate a certain amount of work into one heat, more steam may be abstracted from the boiler than would be consumed in that period by a steam-engine of similar dimensions, and it may be necessary to have a larger boiler which, by its store of heated water, may renew for a given period the steam that is abstracted by the hammer. The steam is seldom cut off to work so expansively as in a steam-engine, and the strokes of the hammer are often more rapid. Moreover, the hammer-valve is opened and shut so suddenly as to render the boiler more liable than an engine-boiler to priming.

Steam worked expansively.

Hammer bed-plates.

Foundations.

Stone or concrete.

Timber.

Piles.

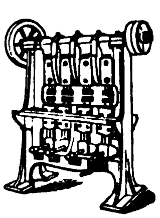
The anvil has to be fixed with great care under a steam-hammer, so as to receive the blows fairly and in a right line. Sufficient weight and solidity to absorb the blows are afforded by heavy anvils, and in the larger machines elaborate and costly foundations are necessary. Stone or large masses of concrete are used as a basis, but frequently timber is placed immediately below the anvil base plate to afford some elasticity to the blow; this plan reducing greatly the destructive effect of the blows, both on the anvil and the foundation beneath it. The timber (oak or pine are usual kinds) is laid horizontally, as there is little elasticity in vertical baulks, but sometimes for soft or marshy ground a solid group or mass of piles is driven to make a firm foundation below. The timber is carefully adzed or planed to afford a true bearing for the bed-plate. Special machines have been devised for planing the bed-plates after they are fixed; and in the case of the larger hammers, temporary furnaces have even occasionally been erected at or near the hammer, so that the anvil and base-plate, too large to be transported, may be cast *in situ*.

Prices of hammers, how compared.

The principal points to notice in comparing prices of steam-hammers are the diameter and stroke of the cylinder, the actual dead weight of the falling parts (the rating of different makers may not be on the same basis in this respect); the accuracy of the fitting in all the jointed parts; whether the bottom of the framing is planed where it fits upon the base-plate; whether the base-plate is itself planed; and the material of which the tup or hammer is made. Wrought iron or steel is best, but cast iron has often to be used for hammers rated above 20 cwt. because of the expense. In small hammers the endurance depends also on whether there are slides or guides to the hammer-head, whether the anvil is separate from the framing, and is machined to fit exactly into the base-plate.

Inferior hammers.

Hammers made too cheaply are often defective in some of the above points, and their rapid deterioration far more than outweighs any saving in first cost. Cheapness is sometimes obtained in small hammers by casting the framing and anvil-block in one piece; and sometimes also by making the cylinder and the framing in one piece, without any guides for the piston-rod.



234.
Forging-machines.

In a description of steam-hammers, reference may be made to *Forging-machines* driven by wheels or belts. Such machines, known sometimes as power-hammers, have either a single tup or have a series of stamps worked by cams or eccentrics, and capable of giving from 500 to 800 blows per minute. In the making of small light

How used. forgings, such as those for fire-arms, machines of this sort are very useful for reducing rapidly the size of the piece of iron presented to them. The shape of the various stamps can be varied, so that the smith has in effect a variety of tools to work with; or, by placing the forging below each stamp in turn, it may be brought down to the required size. Machines of this sort range in price from £100 to £200, and require about one horse-power to work them. In other cases small forgings are shaped in dies by a few blows from a falling tup, which is lifted by a power-pulley to a height and at a speed determined by the workman, who pulls a lever for each blow.

Design and choice, how determined. The most appropriate steam-hammer for any particular purpose can be designed or chosen only on the basis of the following information.

Purpose. 1. The *nature of the Trade* and the average and maximum size and weight of the forgings to be made. If the forgings are, in regard to shape and size, to be constantly alike, a hammer may be specially designed to suit them.

Arrangement of smithy. *See also page 771.* 2. A *Plan* of the smithy, showing the doors and windows, the various hearths, furnaces, cranes and other accessories, or the places available for them; also the capacity and position of the boiler for supplying the hammer with steam, or the direction from which the steam-pipe will be brought. If no contiguous boiler is available, the hammer can be worked by compressed air brought a considerable distance from the storage-container of an air-compressor, which may be worked as well by water as by steam. Where the work is intermittent, this plan may be cheaper than the keeping warm of long lines of steam-pipes. Not only a plan but a vertical section of the smithy should be supplied, showing the height available. It is obvious that information on these points is needed, to allow of the valve-levers being put in the most convenient places, and to afford the most convenient access for forgings and for the erection of the necessary cranes.

Foundation described. 3. The nature of the *Foundations* on which the hammer and anvil are to rest, and the solidity of the walls of the smithy and neighbouring walls to resist concussion. If there is no suitable stone in the neighbourhood, the expediency of sending with the hammer cement for making concrete should be considered, or the cost of timber piles and pile driving. *See page 849,* PORTLAND CEMENT.

4. The facilities for *Transport*, and the maximum size and weight of the pieces that can be carried to the site.

Working of hammers objected to.

5. The likelihood of *Objection* to the hammer on the score of nuisance. The noise and concussion may be minimised, but the working of large steam-hammers is generally prohibited in the central parts of large cities.

Circular hot-saws.

Circular saws for cutting hot bars of iron or steel are often found useful in engineering factories, though they are made principally for rail and bar-iron rolling-mills. The saws, which are made of special steel, range from 30 in. to 60 in. diameter, and run at velocities of from 2000 to 4000 periphery-feet per minute. In some cases the bars to be cut are moved against the saw; in others, the framing which carries the saw is suspended like a pendulum, and the revolving saw moves forward against the bar.

See also page 757, COLD SAWS.

Hydraulic smithing-machines.

Hydraulic smithing-machines are better suited than steam-hammers to some of the processes of fashioning iron or steel into shape while hot, the steady pressure of a hydraulic ram having an effect quite unlike that of the percussion of a steam-hammer on an anvil. Steel ingots or iron blooms can be squeezed down into slabs preparatory to rolling, and forgings of awkward shape may be so pressed in dies. The bending of T, L or ⊔ iron stiffeners for girders or ships' frames also exemplifies the kind of work to which the hydraulic press is well applied in a smithy. By means of dies or swages the same press can be adapted to a great variety of shapes. As, with a working pressure of 2000 lbs. to the square inch, a ram of 9 in. diameter will exert a force of 50 tons, it is obvious to what important uses such power can be applied. A 50-ton press with a stroke of 1 ft., complete with pumps, accumulator and pipes, but exclusive of motive power, dies or swages, costs about £400. If the pressing operation is only performed thirty times per hour, an engine of 3-horse power would suffice for pumping up the accumulator, or that amount of power would be abstracted from a line of shafting running for general purposes. There is hardly any limit to the size and weight of these machines, some of which impose a pressure of 5000 tons. Hydraulic presses may be used in combination with the steam-hammer, giving the final and exact shape to forgings hammered approximately into form, or may be used for "upsetting" a forging which is afterwards finished under the steam-hammer. This combination of methods is well exemplified in the manufacture of links or "eye-bars" for bridges, more usual in America than in England.

As for girder-stiffeners.

Cost of 50-ton press.

Accumulators.

See page 491.

Eye-bars.

See page 143.

Flanging-presses.

Flanging-presses, for dishing the end plates of boilers, are in common use in all important factories, and the same process is applied to the frame-plates of small bogie carriages, and even to the frame-plates of locomotives. So also, steel railway sleepers and floor-plates for bridges may be conveniently pressed in hydraulic dies. Machines for the above purposes are expensive, because they have to deal with a considerable area of iron or steel. Numerous cylinders and rams are necessary, and the framework of the machine has to be massive to resist the strains imposed.

Pressing of carriage-frames.

Steel sleepers. *See page* 671.

Electric welding.

Electric welding, which may be more correctly designated as electric heating, may be sometimes used with advantage where the pieces are of moderate size, and where the repetition is sufficient to repay the cost of special accessories. The apparatus consists primarily of an electric "transformer" (worked by a steam-engine or other motor) for producing by induction a current of large volume but very low voltage. The current passing through the articles to be treated, the resistance to the low-voltage current rapidly makes the adjacent parts white hot. The heating is rapid and clean, and the parts to be welded are pressed together by hydraulic or screw power when white hot. For the short time during which the actual heating takes place considerable force is necessary, which may be stated approximately as 40 brake horse-power per square inch of sectional area of the iron heated. The process as above described is applicable to bars, and is useful for occasional welding in a workshop where a smith's forge would be inconvenient. Although the weld is strong it hardens the adjacent parts, which should therefore be annealed. Another method is that by which an electric arc, concentrated on the edges of sheets, brings them to a welding heat; or, if inserted in the flaw hole of a steel casting, so heats it as to allow of molten metal being poured in, which renders the defective place again homogeneous.

Transformers. *See page* 265.

Power required.

Another method.

[*See also* THE ESTABLISHMENT OF FACTORIES: THE TRANSMISSION OF POWER: MACHINE TOOLS.]

CHAPTER XXVII.

CRANES. STEAM, HYDRAULIC AND ELECTRIC CRANES.

PUBLIC works and the transport of merchandise on the scale of the present day are only rendered possible by the cranes which are available: and their manufacture ranks with that of machine tools as one of the principal trades on which engineers depend. The catalogues of manufacturers sufficiently enumerate the various kinds of cranes that are made for ordinary purposes and for moderate weights; but the diversity which affords so wide a choice to the engineer is, in itself, often a cause of difficulty for want of some analysis of the different methods employed, and of the special circumstances which, in particular cases, make one kind rather than another applicable.

Choice of cranes.

The various lifting apparatus included in the generic appellation of *Cranes* may for conveniemce be first divided into three principal categories, as—

Cranes classified.

1. Derricks and sheers.
2. Jib-cranes.
3. Overhead cranes and travelling gantries.

Even these broad distinctions—though embracing the great majority of hoisting apparatus—are insufficient; for there are hybrid cranes which come partly within each, and there is also the necessary classification according to the motive power—manual, steam, hydraulic or electric. Moreover, cranes of whatever kind, if for lifting weights

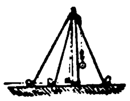
Hybrid cranes.

over 20 tons, need separate consideration, as also do portable as distinct from fixed cranes.

Derricks.

Light pole derrick.

The simple *Derrick*, which is the most primitive kind of hoisting apparatus, may be considered rather as a substitute than as in itself a crane, and it is seldom used except for such temporary work as the lifting into place of girders or roofs. And although for such purposes the weights lifted seldom exceed 10 tons, weights as heavy as 50 tons may be lifted by one derrick-mast or baulk of timber, if occasion requires it. The use of the single derrick is greatly limited by the necessity of keeping it nearly vertical, a condition which indeed puts it outside a strict category of cranes. The ordinary derrick is a spar or mast, square timbers being employed only where a round mast cannot be conveniently obtained; a fir scaffold-pole suffices for light weights and moderate lifts. A bundle of such poles is often lashed together to form a longer or stronger derrick than a single one affords; but it is always better to have one strong mast than such a compound substitute.



235.

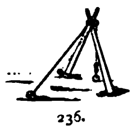
Stability depends on guy-ropes.

Power from winch.

Cost of hoisting-crabs.

See also page 794.

While the load is supported by the mast or pole, the stability of the apparatus depends entirely on the guy-ropes, of which there must be at least three. The hoisting power is obtained from a crab or winch, which for safety to the workmen should be at a distance of not less than the height of the derrick; and the chain from the winch-barrel is taken through a snatch-block at the foot of the derrick to a set of sheave-blocks at the top, the power being multiplied and the speed of lift diminished in the usual way according to the number of pulleys. A derrick is often used in the erection of structures because of its portability, and while it is movable, the winch may be kept stationary, the chain being led in various directions by pulleys and snatch-blocks. An ordinary hoisting-crab or winch for working by hand costs from £5 to £20, according to its power, but if equipped with a steam-engine, from £60 to £100, and if with a boiler also, the prices range from £100 upwards.



236.

Sheers.

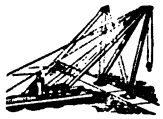
When two poles or masts are used, the name of *Sheers* is generally substituted for that of derrick; two guy-ropes only are needed. The sheers may be inclined; and by altering the inclination they may serve, to some extent, the part of a moving jib or wharf-crane in transferring goods which are being hoisted, thus bringing the apparatus within the definition of a crane. As the sheers have lateral stability, one guy-rope before and one behind suffice, but if, as at the end of a jetty, there is no place for a forward guy-rope, then a pole must be substituted for the hinder guy-rope. Sheers of this sort are sometimes preferred to fixed cranes where hoisting has seldom to be performed, because the apparatus is cheaper and can be more easily removed than a crane. Except for the simplest cases and for very small weights, the winch gear is entirely separate from the sheers; for there is not much room on the sheer legs for a barrel or drum of proper size, and a small barrel is to be avoided if possible.

See page 794

Timber sheers.

Derrick-poles and sheers are generally made by the user from the most suitable timber obtainable in the locality; the winch, chain, snatch-block and set of sheave-blocks, which complete the apparatus, being separate articles to be purchased. The best pieces of timber are generally selected for derrick-poles, and the price rapidly advances with their size, so that when a mast 25 ft long could in England be purchased for 2*s.* per cubic foot, one 50 ft. long would probably cost 3*s.*, and one 70 ft. long 4*s.* per cubic foot.

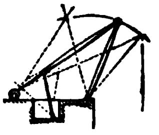
Cost.



237.

Permanent sheer-cranes.

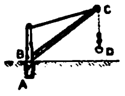
The principle of the derrick and sheers has been elaborated in various ways and adopted for different kinds of permanent cranes. Lofty sheers for the masting of vessels are a notable example, as also are those (generally formed of three masts) used at docks for hoisting pieces or packages weighing more than 20 tons into ships. In these cranes the masts are made of hollow wrought iron or steel, and are hinged at the foot, so that the inclination can be so altered as to transfer the load from a ship's hold to the landing-quay. This can be performed by pulling back the foot of the hinder mast by a horizontal screw moved by a steam-engine, or, where there is not sufficient ground space available for the horizontal method, by pulling the foot of the hinder mast down below the ground level as into a well. But as by neither of these methods is the hinder member of the derrick pulled directly in the desired line, a third method has also been adopted (Fig. 238) by which the pulling-back force is better applied.



238.

Cranes with projecting jibs.

The great majority of cranes are those with projecting jibs, the name of crane, indeed, originally having been given to apparatus of this kind. The various types now in use may be best described by classifying them according to the method of giving stability to the jib. On this depends, to a large extent, the general construction of the cranes; and as the choice of crane depends mainly on the local circumstances, which may make one method rather than another profitable or convenient, it is one of the leading points to be considered.



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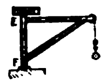

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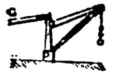

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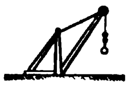

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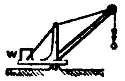

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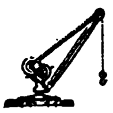


244.

Assuming that the vertical post of a crane has a bottom pivot on which to rest and turn, the stability to withstand the leverage of the jib when pulled downwards by a load is obtained either—

(*a*) By continuing the vertical post to a pivot A, so low down that it can, as one end of a lever A, B, C, working on the fulcrum B, withstand the downward pull at D. The post may either revolve on its pivot, or, as is more usual, the lower part of the post may be fixed, and the crane made to turn on it (see also Fig 245).

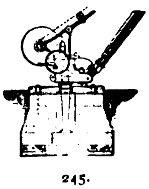
(*b*) By holding the vertical post at an upper pivot E as well as at the lower pivot F, the loaded jib being then supported like the end of a cantilever bracket (see also Figs. 246, 247, 248).

(*c*) By anchoring back the top of the vertical post, either by means of a rigid backstay G to some independent structure, such as a wall, or to the ground, or to the base of the crane itself (Figs. 242, 243), so elongated as to afford a sufficient angle; or, if the distance be too great, or no convenient support for a rigid backstay be available, by means of wire ropes (Fig. 249).

(*d*) By balancing the jib and its load by a weight W behind the vertical post, this method of counterpoise being often combined with methods *a* and *c*.

Cost of wharf-cranes.

The advantages and drawbacks of the above methods may be further elucidated as follows. The plan (*a*) of continuing the crane-post or the pivot on it which turns to a bearing below the ground is suitable for permanent wharf-cranes where no overhead support is available, the expense of the foundation being justified by the unobstructed space which is left at and above the ground-level. The depth of post which will suffice depends on the weight to be lifted. Thus, for weights up to 3 tons, sufficient stability may be obtained from one pivot resting on and revolving in a wide base-plate on the ground-level. A crane of this sort costs from £50 to £100. But for wharf-cranes of more than 3 tons capacity, the vertical post is generally taken down below ground to a depth of from 4 to 10 ft. Such cranes cost from £120 for 3 tons to £500 for one of 15 tons; but if fitted with steam-engine and boiler, these prices are more than doubled.



245.

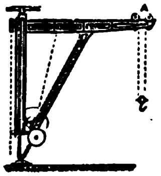
Crane foundations.
See also page 471.

In good solid ground, a pit may be excavated, and an iron casting for holding the pivot built into masonry or concrete. Or, on loose ground, piles may be driven, a space excavated within and enclosed with sheet-piling, and a solid mass of concrete filled in below and around the ironwork of the crane. Or, groups of piles or cylinders may be sunk, as in a bridge pier, and the pivot supported on cross-beams, which are sometimes then embedded in concrete. Occasionally, in difficult cases, such as in loose or marshy soil, the cost of foundations bears a high proportion to the cost of the crane, and renders the consideration of other kinds of cranes expedient.

Cranes on landing-piers. *See page* 131.

Where a crane is to be fixed on an iron landing-pier, a central cylinder may be braced to smaller surrounding cylinders or screw-piles and to the contiguous structure. It may be said generally that wharf-cranes are the most expensive kind of cranes.

Cranes with an upper pivot.



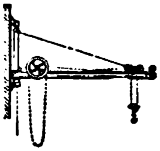
246.

Foundry-crane.

(*b*) Cranes with a vertical post pivoted at the top as well as at the bottom are the cheapest kind when, as is usually the case, some existing structure is available for the upper support. Thus, in a foundry the crane is pivoted at the top to one of the roof-beams, strengthened and stayed for the purpose; in a smithy, to the wall (Fig. 247); in a warehouse or engineer's workshop, either to a wall or to a roof-supporting column. In the latter case, the column may serve as the crane post, the horizontal jib of the crane grasping the column at a recess or neck made for the purpose. This arrangement somewhat resembles that by which a radial drilling-machine revolves on a column. Cranes held at the top of the vertical post are more suitable than any other kind for the horizontal jib which is necessary in a foundry or smithy, to allow the moving carriage A from which the load is suspended to be traversed or "racked" in and out—a most important and necessary operation where the crane is so employed. For, if a crane have a slanting jib, which is generally the case in classes *a*, *c*, and *d*, the radial distance of the load from the vertical post can only be altered by raising and lowering the jib—a method which, though sometimes appropriate and convenient in a wharf-crane, is quite unsuitable where the traversing must be exactly regulated without alteration in height. In foundry-cranes the winch-gear and chain-barrel are attached to the vertical post, and hand power is generally employed, although for lifting heavy weights a steam-engine, or an electric "driver," or hydraulic power can be employed. Foundry-cranes are often made of wood, and range in price from £100 for a 4-ton crane to £200 for a 10-ton crane. If made of iron, the cost ranges from £200 for a 5-ton crane to £500 for a 20-ton crane.

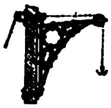
See DRILLS, *page* 744.

In a smithy-crane, for weights up to 5 cwt., winch gear is seldom employed, hand-power being sufficiently multiplied by sheave-blocks suspended from the travelling carriage. For large smithy-cranes—those, for instance, which are adjuncts to steam-hammers—the power



247.

Smithy-crane.



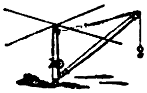
248.

Warehouse-crane.

is generally brought from the outside, either from steam-driven winch-gear or hydraulic apparatus, and is led through guiding-pulleys to, and along, the horizontal jib. A similar plan is also usual for cranes of this class used in warehouses and workshops ; small water-engines or gas-engines being often employed as motors. Light "whip" cranes for lifting weights up to 1½ tons are often made on this plan.

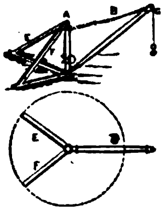
See page 790.

(*c*) Stability of jib, afforded by one or more stays anchored to a fixed structure or to an elongated base, has the advantage of making the crane independent either of insertion in the ground on a solid foundation, as in method *a*, or of an upper support, as in method *b*. Indeed in some cases rigid struts are avoided, and the space they occupy saved, the staying being entirely by iron or steel wire ropes, and if points of attachment are available on every side the jib may revolve freely. This plan is often adopted in America for cranes elevated on lofty staging, distant supports being then available for the wire ropes. But in England, rigid struts or stays of timber are preferred, and the horizontal or inclined backstay may be anchored to a tree or wall ; but as convenient points of this sort are not often available, it is more usual to anchor the back members to the base of the crane itself, prolonged for the purpose. Cranes of this sort are very useful on public works where a temporary hoisting apparatus is required, or one which can be moved from place to place ; and they are also convenient where, from the loose nature of the ground, foundations would be difficult ; or where, as on a landing-jetty or elevated staging, there may be nothing above or below the platform for supporting the vertical posts. Subject to various modifications, the cranes are made with two, and sometimes three, horizontal members framed together, and so extended as to afford points of anchorage for two inclined back members, E, F ; the upper pivot of the vertical post being thus stayed with a favourably wide angle at A. Such a crane has in itself sufficient stability for moderate weights ; but when heavy weights have to be lifted it is usual to increase the stability by loading the base members either by the weight of a steam-winch and boiler, or with stone or kentledge, or by tying them to the ground, additions of this kind bringing the crane into category *d* (Figs. 242, 243). The inclined jib is hinged at the heel C, so that by means of the back chain B, which holds it to the vertical post, it can be raised or lowered to alter the radius. The lifting power becomes greater as the point G is drawn back, and the process of lifting may be, and often is, partly performed by thus drawing



249.

Cranes stayed by wire rope.



250.

Temporary cranes for public works.

Lifting power according to angle of jib.

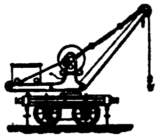
back the jib. As will be seen from the plan, a crane of this sort commands a radius of three-fourths of a circle; but in practice it is seldom effectual for more than two-thirds—a range wide enough for the majority of purposes; and the design of the crane and the disposition of the stays must be such as to afford sufficient stability for any position of the jib. Cranes of this sort are often substituted with advantage for overhead travelling cranes or gantries, compared to which they are—especially on elevated stagings—generally cheaper and more convenient. These cranes are extensively used; they command a wide area, have a high lift, the radius can be varied, and the cranes are cheap. They have, however, the inconvenience—which sometimes prohibits their use—of occupying much space. The prices range from £50 for a 1-ton crane with 25 ft. radius to £150 for a 5-ton crane with 35 ft. radius. If an engine and boiler be added (which may be utilised as a balance-weight) the prices would range from £180 to £450.

Occupy much space.

See page 797.

Movable cranes.

(*d*) Stability of jib afforded by a *Balance-weight* is one of the commonest methods, and is especially useful in a movable crane where no permanent anchorage is possible. The winch-gear is so placed that its weight is effectual, and in a steam-crane the weight of an engine and boiler, and sometimes also of a feed-water tank, is often added to make up the required stability. In stationary cranes the balance-weight may be permanently fixed, but where the crane is on a movable truck, as in a factory yard or on a railway, the weight can be drawn inwards when travelling, and the jib lowered for passing under bridges or doorways. On a railway, of course, the width of gauge is established, and the crane-carriage must be arranged accordingly. As the length of the wheel-base is generally greater than the width, which is of course limited by the gauge, a crane stable enough when the jib is in a line with the rails may overbalance when projecting sideways, and anchorage to the rails may be necessary. But when the crane is thus attached, care must be taken that the permanent-way be not disturbed, and, if necessary, the rails must be weighted. Even the standard, or 4 ft. 8½ in. gauge, is not sufficient for cranes lifting more than 3 tons, without any other support than their own width of base and weight allow. But sometimes cranes are wanted on the mètre or 3 ft. 6 in. gauge, and such a width is insufficient even for the weight of the unloaded jib when projecting sideways, and the crane must be so propped or anchored during lifting as to be in effect a fixed or stationary crane. This is gene-



251.

Cranes on narrow gauge.

rally effected by means of two light projecting beams clipped to the crane-carriage and packed or propped at the outer ends, the packing pieces being so arranged as to be readily withdrawn when the crane has to be moved. When the rails have to be laid down specially for the crane, a width of 5 ft. should be provided for lifting weights of from 2 to 5 tons; a width of from 8 to 10 ft. for weights of from 8 to 15 tons; 12 or 14 ft. for weights between 15 and 20 tons; and 16, 18, or even wider gauge for still heavier loads, although these gauges may be slightly narrowed if the full space is not available.

Strong cranes on wide gauge. *See also page* 808.

Jib-cranes made of wood or iron.

Jib-cranes are made either of wood or iron, and even in cranes otherwise of iron the jib is frequently made of wood, which is well suited to the compression and side-strains to which it is subjected. In beginning to lift a heavy weight, the inertia to be overcome causes severe side-strains on the jib, which, though strong enough to sustain the suspended load, might be twisted sideways and broken. Wooden jibs have been generally preferred for cranes up to 2 tons; between 2 or 8 tons wood or iron has been used; but for cranes of all sizes up to 8 tons iron is now generally preferred. Beyond 8 tons any single piece of timber becomes too bulky, and for cranes between 8 and 15 tons it may be said to be entirely discarded. But for very large cranes timber again becomes applicable. To resist the side strains, a wide or box section of jib is most effectual, and for heavy loads an ordinary H or girder section would not be sufficient, and it is generally found cheaper to frame the jib of timber than to dispose an iron framing in a suitable manner.

Wooden jibs for small power.

Iron jibs.

Wooden jibs for very large cranes. *See page* 809.

The lifting power in a crane is generally obtained by ordinary winch-gear, which multiplies the original motive force by a train of toothed wheels. In small and simple cranes *Single power* is sufficient; that is to say, there is one multiplication only, a small toothed wheel or pinion on the spindle to which the winch-handles are attached working into a larger wheel on the shaft which carries the barrel. This method is, for instance, sufficient where the power is afterwards multiplied by sheave-blocks, as in lifting by a derrick; but for weights above 2 tons, *Double power* or even *Treble power* in the crab becomes necessary, a simple movement changing the wheels from double to treble gear, according to the weight to be lifted. Of course, for every multiplication the speed becomes less, and it is only in the case of very large cranes that a third multiplication is attempted, an

Single power cranes.

Double power.

increase in the original motive power being generally preferred. And even in large cranes where *Treble gear* is provided, it is reserved for heavy loads, and the single or double gear is ordinarily employed. Sometimes the power is multiplied by passing the chain, after it leaves the jib, through single, double or treble sheave-blocks; but this method, though often necessary, has the disadvantage of increasing the length of chain to be wrapped round the barrel, and therefore rendering necessary two or more laps of chain, which is undesirable.

Treble gear.

Further power by sheave-blocks.

It is important that the barrel should be of ample size, primarily because a rope or chain winds most easily on a large drum, and (in the case of a chain) with less strain or surging in the links; and secondly, because it is desirable to have the drum so long and large that a single lap of the chain, repeated if need be all along the barrel, may afford sufficient length for the highest lifts. For as the drum is one of the train of wheels by which the motive power is multiplied, the alteration in its effective diameter, which takes place if a second lap of chain occurs, alters the proportion of the wheels. As the circumference of the barrel becomes greater, each revolution gives a greater lift, and the motive power has to be proportionately increased. This is especially inconvenient in the case of hand-cranes, where there is not the same reserve force as in a steam-crane, and where the increased resistance caused by a greater diameter must be neutralised, either by a slower and less effective exertion, or by bringing into play in the middle of the lifting operation another and slower sets of wheels. Sometimes the lapping of the chain on the barrel is avoided by passing it only once or twice round and then taking it away behind, as is done often on a capstan, or into a pit below the crane; but as an iron chain on an iron barrel is apt to slip, the barrel must be tightly wrapped with rope to afford a grip for the chain, or made with projections to hold the links, as is done with pitch-chains.

Winding-barrels.

Made large to avoid lapping of chains.

Warping-capstan.
See pages 610 *&* 803.

Of course, where the chain is but small—for instance, in cranes lifting about 1 ton—the lapping of a light chain will not materially affect the diameter of an ordinary-sized barrel; but, as a rule, the apparatus is distinctly the better if the lapping can be avoided. Obviously, also, much depends on the height of lift, which determines the length of chain; but, if circumstances allow it, the condition of a single lap is often prescribed by engineers in their specification for cranes, such a stipulation, however, adding considerably to the cost of those over 10 tons capacity.

Single lap on barrel.

Screw and worm-wheels instead of spur gear.

Detached winch.

For lifting weights over 25 tons, numerous trains of wheels may be avoided by substituting screw and worm-wheels for the ordinary spur gear; and worm-wheels have the advantage—which is useful sometimes also for smaller cranes—of lessening the liability to slip or run down, and a weight can be lowered or adjusted with great nicety and safety. Another method of applying power is to detach the winch-gear from the crane altogether—a plan which allows the use of a large winding-barrel and gear, affords more room round about the crane for attaching and detaching the load, and the further advantage of allowing the chain from the winch-barrel to be led away and used for a variety of purposes and at a considerable distance. On board ship the winch may thus conveniently be kept separate, and the chain be taken to hoisting-gear attached to the ship's yards; or with still more advantage in public works, where derricks or sheers may be moved from place to place or elevated on scaffolds, and the chain led through pulleys and snatch-blocks from a winch permanently fixed in a convenient place.

As on ships.

See also page 800.

Power cranes, where useful.

Compared with manual cranes.

The expediency of substituting *Steam* or other artificial power for hand labour depends rather on the speed of hoist and frequency of the operation than on the weight to be lifted, for, if time be granted, the weights dealt with by the great majority of cranes can be lifted by hand power. In comparing manual with other forces, it must be taken into account that two men can work more effectively and safely, and do more work proportionately than one man, because there are certain dead points in each revolution of the winch-handles at which the force is not advantageously applied. In designing cranes it appears better, therefore, to take as a basis of calculation two men as the unit of force. The usual radius of the winch-handles is 16 in., making a circle of 32 in. diameter, or a circumference of about 100 in.; and, allowing 30 revolutions per minute, the handles each travel 250 ft. per minute. Assuming, further, that each man exerts during the whole revolution an average force of 30 lbs., or the two men 60 lbs., and multiplying this by the 250 ft. travelled, a total of 15,000 foot-lbs. is exerted, or nearly ½ horse-power. And if from this one-third be deducted for friction of the crane itself, there remain about 10,000 foot-lbs. as the nett result of two men per minute. This equals a load of 1 ton lifted about 4½ ft. per minute, or 10 tons lifted about 5 in. But in applying such a calculation as the above, which is necessarily based on certain assumptions in

Power as applied to winch-handles.

Foot-pounds per minute.

See page 568.

regard to the force applied to the handles—the number of revolutions and the loss by friction, all of which are liable to variation—the special circumstances of each case must be taken into account. Strong men can exert much more than 30 lbs. if for a short and intermittent load, while for continuous work, with few opportunities for resting, a less result must be reckoned. In England, 25 lbs. per man is generally prescribed as the basis for calculating crane power in the Government dockyards, but for continuous work even this should be reduced. In regard to the friction, every additional train of wheels or multiplication of power increases it. In powerful cranes the moving parts are heavy, and, after the highest skill has been used to design and make the parts in the most suitable manner, the force required to work them, even with no load suspended, is very great, three or even four men being required to work a 20-ton crane unloaded. Two men will suffice for loads of 5 tons, although it is usual to employ four men when the load exceeds 4 tons; but when two men have thus to work at each handle, they are less conveniently placed for exerting themselves. It is very dangerous to have a crane under-manned.

Manual power varies.

Friction of crane wheels.

Friction of powerful cranes. *See also page* 515.

Steam power has proved so effective and convenient for cranes that it is the exception to its use rather than the rule that needs justification. For lifting weights where, from the nature of the work or the infrequency of the operation, there is ample time to allow the men to work slowly and to rest frequently, hand power is generally preferred. So also where continual adjustment is needed, as in a foundry-crane, hand power is still frequently employed, although in large modern foundries overhead gantries or travelling cranes are often used, to which power may be supplied, either from a contiguous engine or from constantly-running shafting or rope. Electric transmission and electric motors have largely superseded these methods. Even for a wharf-crane, if seldom employed, there may be no advantage in having steam power, which might require the bringing of steam into cold pipes from a detached boiler, or the lighting of a fire in a contiguous boiler, and very often the keeping the engine in order by a skilled engine-driver. But where, as in a factory, the chain can be worked from some machine inside connected with a running engine, such power may be utilised with advantage. And in very large cranes, the extra cost of a steam-engine may bear so slight a proportion to the total cost of the crane, and the operation, though infrequently performed, may be so important, as fully to justify the cost and time

Steam power.

Foundry-cranes. *See page* 791.

See ELECTRIC, *page* 807.

Steam-pipes. *See page* 483.

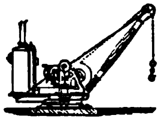
Steam power for large cranes.

Hand power involves too numerous wheels.

Saving of time by steam-cranes.

of getting up steam. Another point to be considered in choosing between hand and steam power is, that the former may necessitate an extra train of wheels to obtain the required force, and this extra train adds considerably to the friction, and therefore to the unprofitable expenditure. It is, however, speed rather than power which renders steam so useful, and steam-engines are employed more often for small than for large cranes. Thus, in the loading or unloading of a ship, steam saves much time, and therefore much money. The expediency of having steam power may be to a great extent determined by the proportion which the time occupied in the actual lifting bears to that occupied in the shackling or preparatory work, and the unshackling after the lifting is accomplished. For if fifteen minutes is occupied in shackling or arranging the sling chains, it is of less consequence whether the actual lifting occupy one minute by steam or ten minutes by hand, than in cases where the slinging and shackling occupy only one minute; then the speed of the steam-engine affords a greater proportionate saving, which may be profitably utilised.

Steam-cranes for hoisting cargo. *See page* 682.



252.

See page 577.

Prices of steam-cranes.

Steam-cranes are used to the greatest advantage—in public works, for the rapid and continuous hoisting of excavated soil or of building materials; and at docks, for hoisting cargo into and out of a ship's hold. The speed with which all the operations of hoisting and lowering the load, of altering the radius by elevating and lowering the jib and of slewing round are performed, is so enormously in excess of what any hand-crane could perform, as to amply repay the greater capital expenditure and the current expenses of coal, supervision and maintenance. The actual power is obtained much more cheaply by fuel force than by manual force, notwithstanding the fact that crane-engines burn more coal per effective horse power than larger fixed engines. Except in special trades, most of the pieces or packages in a miscellaneous cargo are of moderate weight, and it may prove best to use light cranes which work easily and quickly, leaving heavy packages to be lifted by tackle from the ship's yards, or, if over five tons, by powerful wharf-cranes, to which the ship can be moved for the purpose. A steam-crane with a radius of 15 ft., complete with boiler, and with gear so arranged that the hoisting, lowering, and slewing are all performed by steam power, will cost from £270 to £320 for lifting a weight of 1½ tons; £350 to £450 for a weight of 3 tons; and from £450 to £600 for a weight of 5 tons. If a crane is to revolve on a fixed base, the foundation-plates and bolts will cost about the same as a carriage on wheels if the crane is to be made movable. If, however, the crane is to travel on a railway, the carriage and wheels must be stronger; and the necessary appurtenances of buffers and springs add from £20 to £50 to the cost. Locomotives are sometimes made with crane jibs. The power of a crane should be specified by the weight which can be safely lifted when the jib is projected to the full radius, as such cranes are generally so made as to allow heavier weights to be lifted when the jib is raised and the radius reduced.

See pages 600 & 682.

Crane boilers. *See page* 577.

The small size of the engine and boilers, the quick speed and intermittent nature of the work, all hinder an economical use of fuel, and as the cost of coal generally bears but a small proportion to the work done (which is not to be measured by the mere foot-lbs. lifted but by many secondary considerations), the endeavour is rather to construct the boiler so that it will generate steam quickly, and with a minimum of size supply sufficient steam for rapid working, than to obtain a minimum expenditure of fuel. Vertical boilers with cross tubes are the kind generally used.

Steam-cranes severely strained.

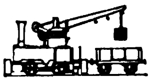
The work of a steam-crane or winch is one of the severest kind, and the sudden stoppages and reversings cause jerks and shocks upon all the working parts. The value and durability of the machine depend greatly on the quality of the material and workmanship; and cheapness, if obtained by inferiority in these respects, is ultimately very expensive. Steel, the best wrought iron and high-quality cast iron are essential, and all moving joints should be case-hardened, Steel, gun-metal or malleable cast iron are often substituted with advantage for cast iron in toothed wheels. The chains and hooks should be made of the very highest quality of wrought iron, which facilitates sound welding and is durable against repeated shocks and strains. Steel is never used for such purposes. The shoulder of the hook where it presses on the shackle or pulley frame should move on balls or roller bearings, this being especially useful in cranes lifting more than 2 tons.

See page 546.

Ball bearings. *See page* 744.

Cargo-cranes must be movable.

For loading and discharging ships, the cranes must be movable, so as to take various positions to suit the hatchways of vessels; and, in order to avoid obstruction to lines of railway upon the quay, the crane may be elevated on a travelling stage through which the railway wagons can pass. Movability is even more necessary for cranes used on public works. Therefore, cranes so employed must be complete and self-contained on a travelling carriage with engine and boiler. Steam-cranes, when made self-propelling, are, when used at ironworks,

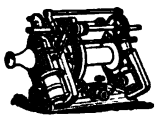


253.

See also page 600.

Engine detached from crane.

See pages 603, 609, 611.



254.

stone quarries and other places with railway lines, often employed as locomotives for shunting wagons. Or at steel works, the crane which lifts the molten steel or ingots carries the suspended load and deposits it where required. For wharf and other fixed cranes, it is often convenient to bring steam from some adjacent boiler, and only the engine is attached to the crane itself; and though this plan is most easily adopted for fixed cranes, steam-pipes can be arranged for movable cranes also. Sometimes the plan of detaching the power is carried further, and the engine with its winch-gear and barrel is fixed in an adjacent building, and the chain brought to the crane through guiding-pulleys. This plan is often expedient in city warehouses or work-shops, where steam-boilers, or even only an engine on the crane itself, would involve risk and annoyance. In small cranes this plan is frequently adopted, the power from a constantly-running drum near the crane being brought into action by fast and loose pulleys, or by a friction clutch, or other simple means. Where the boiler and its smoke are alone objected to, the power is often conveniently obtained from a gas-engine, water-engine or electric motor. On public works, detached winch-gear, as already described, is sometimes preferred, and on board ships a steam-winch with projecting capstan is in this way used for raising the anchor, warping cables, and other purposes, as well as for hoisting; but steam for such cranes is generally supplied from a detached boiler, even in a steamer. To afford equal and continuous power without a fly-wheel the engines for these winches are made with two cylinders, and with a link-motion for reversing. The cost of steam-winches of this kind ranges from about £80 for a winch with 5-in. cylinders for lifting 2 tons, to £130 for a winch with 8-in. cylinders for lifting 5 tons.

Compressed-air engines.
See page 496.

Air power expensive.
See page 499.

Compressed air is used for working winches and cranes under certain circumstances, as, for instance, in and about mines, quarries and tunnels whither steam cannot be conveniently conveyed, or where steam would be unendurable. Unless, however, air-compressors are already provided for working rock-drills or other purposes it is seldom expedient to transmit power in this way, and hand power or electricity is generally preferable.

Hydraulic-cranes.
See page 485.

Hydraulic-cranes may be used with advantage in many cases where any other kind would be costly or inconvenient, or insufficient; and the facilities which water affords for transmuting, transmitting, distributing and concentrating power, are seen to their best advantage in the case of cranes worked by the "accumulator" system. Where hoisting has to be done quickly, mechanical power of some kind is necessary, but if steam be employed and have to be worked at long or irregular intervals, much expense is involved in maintaining, ready for action in each crane, steam power sufficient for the maximum service that may be required; and the useful or effective work done bears but a small proportion to the power consumed, and to the expenses of supervision. And if, to save the cost and inconvenience of having a boiler at each of numerous cranes, steam be brought in pipes from one boiler, the pipes become cold during each interval of waiting. There is waste and inconvenience from condensed steam; and if this method were adopted for numerous or widely distributed cranes, the aggregate length of steam-pipes would be an insuperable difficulty. The hydraulic system obviates all these objections. A pumping-engine, of force equal to the average service constantly employed in raising the accumulator, stores up a power which can be drawn upon instantaneously by any crane which has been connected by pipes within a mile or more of the pumping-engine; a crane, for instance, in some remote place, required only once a day or once a week, being as readily set to work as others. Thus an engine of 50 horse-power can work numerous cranes having an aggregate lifting power of 500 horse-power, because it is unlikely that more than one-tenth of the cranes will be working at the same moment. The loss of power in transmuting steam-power into hydraulic force, and in keeping a pumping-engine always in steam, is more than met by the conveniences afforded; and stationary engines so employed can be worked with the minimum of fuel, 3 lbs. per indicated horse-power per hour as compared with 10 lbs. in a steam-crane being a fair comparison. The system finds its best exemplification at railway goods-stations or docks, where rapid work at numerous cranes is required but at irregular intervals; or in factories where the accumulator system is utilised for working machine tools.

Accumulator system.
See page 492.

Objections to steam power.
See page 483.

See page 493.

Cranes at railway-stations.

A steam-engine fixed in some convenient place is employed in pumping up the accumulator load, which, pressing on the water uniformly in all the lines of piping, keeps ready at each crane the maximum force. The engine is arranged so as to stop pumping automatically when no power is being abstracted; and if, on the other hand, at any particular moment, all or most of the cranes happen to

One pumping-engine works many cranes.

be lifting simultaneously (a very rare occurrence) and more power is sought than the engine affords, there is only a brief delay till the engine accumulates the necessary force and supplies the demand upon it. If there be only one or few cranes, or only occasional service required, there need be no special steam-engine if there be a line of shafting from which a small pump for the accumulator can be driven; or still further economy may be obtained if moderate but continuous water-power be available for working the pump. Another advantage of the hydraulic system is the great power which may be obtained in cylinders of small size, the ordinary pressure being so much greater than that usual in steam-engines.

Pumps worked from shafting.

Direct-acting hydraulic rams.

In some cases the power is applied directly to a piston or ram in a vertical cylinder suspended from a travelling gantry or from a radiating jib, the lifting hook hanging from the ram. Hydraulic machines of this kind are sometimes used in an engineering factory or shipbuilding yard for carrying portable riveters, and in other cases such rams are suspended over large lathes or other machines for lifting in and out of place the articles operated on by the machine.

Suspended from gantry.

In such situations the ram should be suspended from a rail along which it can travel, or from a radial jib something like that of a smithy crane, so that a sufficient area can be commanded. At arsenals and dockyards, heavy machinery and guns weighing as much as 100 tons, are lifted by direct-acting rams as above described. This system of crane has even been applied to the lifting of torpedo boats or small gun-boats weighing 300 tons.

100-ton crane.

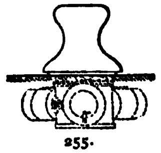
300 tons lifted.

Direct-acting rams.

For wharf, warehouse, or ship's-cargo cranes, it is more usual to supply the power by means of a cylinder, moving-ram, and sheave-blocks, to which the chain is attached; but instead of multiplying the power as is usual in a crane, the high-pressure water affords so much power that it can be extended by means of sheave-blocks worked in the reverse way to the ordinary method. That is to say, a ram, with a stroke of 4 ft., pulling at a pair of three-sheave blocks, drags the chain which issues from the last pulley 24 ft., but, of course, with a power proportionally diminished. In a large terminal railway station, with numerous cranes for loading and discharging the trucks, cranes so worked are extremely convenient for weights of from 5 to 40 cwt., and can be managed by ordinary workmen, who have nothing to do with the motive power at a distance, but who can control the crane by pulling a lever. The high-pressure water can also be applied with advantage to small engines (three-cylinder

Power increased by sheave-blocks.

engines are found most suitable), which, placed below the platform, give motion to capstans for shunting and marshalling the wagons, as a rope passed a few times round the capstan can be instantaneously pulled with great force.



255.

Capstans.
See also page 610.

Usual pressures.

A pressure of from 500 to 700 lbs. per inch has been adopted for hydraulic-cranes as just described; but the apparatus could be as well worked at 1000 lbs., if occasion demanded, without involving the modifications in detail or special precautions which much higher hydraulic pressures would require. The distributing pipes for the hydraulic system are of cast iron, of sufficient thickness to withstand the pressure, and united by strong flanges and bolts. The small branch pipes to the separate machines are usually wrought-iron or steel butt-welded or solid-drawn tubes. A ramification of such main pipes and branches, laid down in and about a railway station, or factory or dock, allows of cranes or other machines being connected at any point at any time, if the main pipes are made large enough in the first instance to transmit the water required.

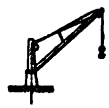
Distributing pipes.
See pages 495 *&* 655.

Hydraulic system expensive.

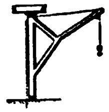
The capital outlay for hydraulic-cranes often forbids their adoption, especially in small undertakings, where the saving to be obtained in the current expense of working would be doubtful or not immediately apparent. As the light cranes for unloading general merchandise are easily worked by hand, it is only at large or busy stations where many such cranes are required that the expense is justified. The system has been widely adopted in England, because the enormous goods traffic at the principal railway stations must be quickly moved. A complete establishment consists of steam-engine, with boilers, pumps, accumulator, and the necessary adjuncts of engine-house, boiler-house, and chimney; cranes, each with a cylinder, ram, pulleys, and chains; and the lines of pipes and valves. As a safeguard against stoppage it is generally expedient to have duplicate engine, boilers, and pumps, which add considerably to the expenditure. Hydraulic cranes of the kind usual at railway stations, with ram, pulleys, and chains for lifting about 30 cwt., cost from £100 to £150 each, the exact sum depending not so much on the hydraulic apparatus as on the projection of the jib, and whether the crane is made according to the method *a* or *b*, already described. Method *a*, Fig. 256, in which the crane depends entirely on a lower pivot, and which is that usual on a wharf, is the dearer; method *b*, Fig. 257, being more often employed in warehouses, and sometimes in goods stations, where overhead roof-beams are available for support

Where justified.

Duplicate engines.



256.
See also page 790.

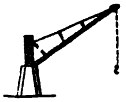


257.

Gas-engines for pumping.

and attachment. The establishment of hydraulic-cranes, including engines, buildings, and pumps, ranges at different railway stations from £4000 to £30,000, a cost which is prohibitory in most private establishments. Where the service required is infrequent or of small extent, some of the expense of steam-engine and boiler may be avoided by the use of a gas-engine, with pump and small accumulator, which are set in motion only at the time when the machinery is needed. This method is, for instance, occasionally adopted for such intermittent service as the opening machinery of swing-bridges. However, for isolated cranes it is generally cheaper to transmit the power by an electric conductor to a small electric motor fixed on each crane.

Electric motors
See page 611.

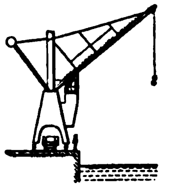


258.

Movable cranes at docks.

How worked.

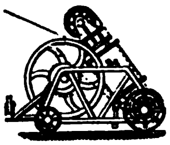
The great convenience of having the accumulator system established in a dock for opening and shutting lock-gates and for warehouse hoists, as well as the objection to steam-cranes because of the risk of fire, have tended greatly to the adoption of hydraulic cranes also ; and those of moderate lifting power have proved most suitable for miscellaneous cargo, the apparatus being arranged for high speed. As cranes of this sort must command the hatchway of a vessel, the radius of the jib must be greater than that of a railway goods-station crane, and must have a much greater height of lift and length of chain, so as to raise cargo from the bottom of a ship's hold, and swing it clear of a railway wagon on the quay. Moreover as such a crane must be self-contained without upper support, it is necessarily more expensive than one of similar power attached to a roof beam. Owing to the differences in the size of ships and in the position of hatchways, cranes fixed on the quay or wharf have proved inconvenient, but the other advantages of the hydraulic system lead to its adaptation to movable cranes rather than its abandonment. There are two different methods of effecting this. As only a limited range of movement is necessary to allow the crane to be placed opposite a ship's hatchway, the power-chain can either be led through pulleys from a fixed hydraulic ram in a contiguous building, or the hydraulic apparatus, being affixed to the crane in the ordinary manner, the water-pipes from the pressure-main can be so arranged with telescopic or swivelled joints as to allow the necessary movement of the crane. To afford sufficient stability to the overhanging jib, the crane carriage is best made with wheels for a wide gauge, a third line being laid down on the ordinary railway track, the base of the crane then being rather wider than shown in Fig. 258, and furnished with wheels. Fixed or movable cranes as above described, with a radius of 28 ft. from the centre post (about 23 ft. overhang from the quay), and for lifting 35 cwt., cost from £400 to £500 each.



259.

Elevated crane.

As movable cranes of this sort hinder the passage of goods traffic on the edge of the quay, the system has been further elaborated by raising the crane carriage and making it wide enough to bridge over the railway on the quay, so as to allow hand-trucks or even railway wagons to pass through. A crane of this sort requires a rail track of about 10-ft. gauge, and a jib radius of 30 or 32 ft. from the vertical post, to allow it to overhang the quay 23 ft., and such cranes are necessarily expensive, costing from £500 to £700; but this expense is justified by the rapid transfer of cargo to or from railway wagons which the system allows. Portable machines of a smaller and cheaper kind can be utilised wherever hydraulic mains are laid down in a dock. These small machines (known as jiggers), have a ram with sheave-blocks arranged on the same principle as in a hydraulic-crane, but without any crane-post or jib. The goods are lifted from the ship's yards, to which the chain is taken from the machine. The height is arranged to suit the depth of hold, the lift of the chain being multiplied not only by the sheave-blocks but by the differential diameter of the barrel. A machine of this sort is easily propelled by hand, and can be attached to a hydrant at any point along the dock or quay. They cost about £100 each.



260.

Portable hydraulic winches.

Hydraulic cranes on steamers.

The hydraulic system has proved so simple and useful that it is even applied for cranes on steam-ships, whose profitable working depends greatly on quick despatch of cargo. While, however, cranes as just described are suitable for miscellaneous cargo, much stronger cranes are necessary at ports where heavy weights have constantly to be lifted. For instance, at some coal-shipping ports, loaded wagons of from 10 to 15 tons weight are lifted and swung round over the ship's hatchway. For hydraulic-cranes of this sort (as is the case generally for large cranes) special designs are required, and no fixed designs or prices apply.

See page 494.

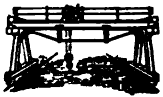
The non-compressibility or want of expansive force in the water is a disadvantage in hydraulic-cranes which has been already explained, as also the risk of stoppage from frost.

Travelling-cranes.

Travelling-cranes and overhead gantries, though made in various ways, form a class of their own entirely outside the cranes just described, the main point of difference being that the weight is lifted by, and suspended from, a bridge or girder supported at both ends,

Command wide area.

instead of from a single column, as in a derrick, or from an overhanging jib in an ordinary swinging-crane. Full advantage is taken of the double support to extend the area commanded by the crane, the width ranging, according to circumstances, from 20 ft. to 70 ft.



261.

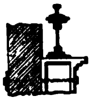
Goliath crane.

262.

Travelling-bridge on fixed staging.

The fixed gallows or gantry is the rudimentary type of overhead crane, a cheap and simple structure of this kind being sometimes used for loading and discharging wagons in a quarry, stone-merchant's yard, or boiler-yard, the articles to be lifted being brought to or taken from the gantry on rollers. It is a simple step forward to fix the uprights on a horizontal sill or base furnished with wheels, so that as a travelling-carriage it can be propelled along a line of rails laid down for the purpose, such cranes as these being known as Goliath cranes. A crane of this sort is cheaper than an overhead bridge moving on an elevated staging, and it leaves a clear space below except at one place where the crane is at work, such an unobstructed area being often of great importance. On the other hand, the fixed staging with a travelling-bridge affords a complete apparatus, more easily worked, and allows two or more travelling-bridges to be at work on the same stage.

263.



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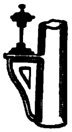


265.

Timber is generally used as material for the staging and travelling-bridge, and timber beams trussed with iron tie-rods can be made strong enough even for wide spans and heavy loads. But wrought-iron or steel girders are also frequently used for the travelling-bridge, and even as longitudinal supports for the rails on which the bridge works. In a factory, a set-off in the wall (Fig. 263) affords such continuous support as to require only a longitudinal sleeper below the rails. Sometimes the girders or beams are carried on brick piers or iron pilasters (Fig. 264) at short distances apart, or on corbels projecting from the wall, or on small brackets (Fig. 265) cast on or bolted to the columns which support the roof. In engineering factories it is important to allow ample headway under the crane, so that the travelling-bridge will pass clear of any lofty machine or structure that may have to be erected. And in large workshops there are sometimes two travelling-bridges at different levels so that one can pass under the other. The motive power is given in various ways. In the simplest cases, for weights not exceeding one ton a rope passing over a grooved wheel of large diameter, as in a whip crane, allows the power to be applied from below. For small cranes and simple cases, an ordinary crab or winch is fixed on the bridge, with gear by which it may be made to traverse the bridge, the forward movement being

Steam-winch on crane.

Quick-running ropes.

Approximate prices.

separately performed by simple gearing attached to one of the travelling carriages on which each end of the bridge rests. Sometimes every movement is performed from below, the forward motion of the bridge, the traversing of the winch on the bridge, and the lifting of the load, being effected by various clutches manipulated by the workman in charge. In powerful cranes, however, it has been usual to have a steam-winch on the bridge, which not only serves for hoisting, but for the traversing and longitudinal movements. An overhead boiler, with the attending inconveniences of hot water and cinders falling, is not wholly satisfactory. In factories, advantage is sometimes taken of a fixed steam-engine to transmit power by a longitudinal shaft the whole length of the traveller, and, the shaft being square in section, the wheels which take power from it slide on the shaft as the bridge travels. Or, power is brought from a fixed engine by cotton, hempen, or wire rope, either of which, if run at a high speed, need be but of small diameter. By this means the lifting and other movements may be managed either from the bridge or from below, but in neither case is there obstruction from steam, or boiler or winch-handles on the crane itself. A 10-ton crane for spanning 40 ft., and arranged to take power from a quick-running rope as above described, costs, fixed in place, but exclusive of longitudinal beams on which the bridge travels, from £450 to £500, according to local circumstances. If strong enough to lift 20 tons, the cost would range from £600 to £700.

Electro-motors.
See page 611.

See VIGNETTE, *page* 787.

The whole question of applying power to travelling-cranes has been modified by the successful application of *Electro-motors*. The easiest cases for this method are obviously those where an electric generator and transmission system are already established for lighting or for power distribution. Even, however, where such a general application is wanting, it may be advantageous to generate electricity for the one purpose of the crane, if any service beyond that of manual power is required. By this means the necessity for belting or ropes constantly running is entirely avoided, as well as the still greater inconvenience of a steam-engine and boiler on the crane. In the desire to minimise the number of electric machines, it has been usual to have only one such motor on the crane, and to direct the force to the different purposes of hoisting, traversing, and travelling by means of clutches or toothed wheels. Since, however, it has been found that small electro-motors can run constantly or intermittently for long periods with no more attention or need for repairs than other simple machinery, it has been found cheapest to apply a separate reversible motor to each of these three movements. A 10-ton travelling crane 40 ft. span, with three such motors, would cost, exclusive of the bare conductor wires along the workshop, from £560 to £600, and if for lifting 20 tons, from £750 to £800. If electric generators are already provided in a factory, the cost of applying the power does not exceed that of a steam boiler and engine on the crane, but even where an electric generator has to be supplied for the purpose, the advantages gained in simple and cheap working will generally repay the extra cost.

Approximate prices.

Lifting by magnets.

When the articles to be lifted are of iron and steel, they may be lifted without hook or sling by bringing into contact with them an iron bar magnetised at will by switching on the electric current. These magnets were at first applied to the lifting of small weights such as pigs of iron, but have been safely used for loads of two tons.

All the types of cranes that have been here described are made in various ways by different manufacturers, whose catalogues afford ample choice. But the diversity of design which the competition of makers affords, and which is available for cranes of moderate power, becomes rapidly less as the size and capacity of the crane increase. For in designing cranes with a capacity beyond 15 tons, every circumstance of locality or purpose acquires enhanced importance, and it is generally necessary or expedient to make a new or modified design. Large cranes are so expensive that the preliminary question of the permanence of the service should be fully considered, as temporary hoisting apparatus can generally be more cheaply contrived. Thus, in the case of public works, if large masses of stone or concrete have to be lifted during a short period; or in the establishment of a factory, the unloading of boilers; or at a fortress, of heavy guns, derricks might be cheaply erected and removed when the work was accomplished. As previously mentioned, loads even as great as 50 tons can be lifted from one mast or baulk of timber, the necessary adjuncts of guy-ropes, crab, and sheave-pulleys being in themselves comparatively inexpensive. For unloading from a ship, however, a single piece of timber would seldom be sufficient, without great risk and difficulty, and sheers formed by two masts would be necessary.

Large cranes need special design.

Derricks.
See page 788.

If, however, the lifting of a heavy weight will periodically recur, then the capital outlay for a permanent crane becomes justifiable. Thus, at a government dockyard or arsenal it is necessary to have a crane strong enough for the heaviest gun or armour-plate; and at a mercantile port where locomotives, large boilers, or guns are shipped or landed, one large crane is generally indispensable. Sheers as shown on page 789 are most frequently adopted for these special purposes. And even on public works to be completed within a limited period, the time may be long enough and the operations so numerous within the period, as to amply repay, by the conveniences afforded, the greater cost of a permanent crane over that of temporary apparatus. At arsenals, dockyards, or mercantile ports, if the weights to be lifted do not exceed 25 tons, a wharf-crane is generally the most suitable kind, and the expense of a self-contained crane according to method *a* has to be incurred. The kind and cost of foundations is then a question of great importance, but if there be great difficulty in regard to foundations then method *b* or *c* affords certain advantages. Jib-cranes are seldom made for loads above 25 tons, permanent sheers or derricks then becoming preferable.

Powerful permanent cranes.

At dockyards and public works.

25-ton wharf-crane.

Foundations.

See a, b, c, page 790.

Some of the most powerful cranes are those which have been designed for lifting concrete blocks in the construction of harbours and breakwaters. As the modern use of concrete has extended, the size and weight of such blocks have tended to increase, and blocks weighing 30 tons are frequently made, and occasionally blocks of 100 tons and upwards. It is not merely the weight which determines the strength of the crane, but the necessity for a far-reaching jib or arm to deposit the blocks; and it is evident that the strain on the crane is in a rapidly increasing ratio to the load as the overhang and leverage become greater. Indeed, some of the machines constructed for lifting heavy weights are outside any ordinary category of cranes.

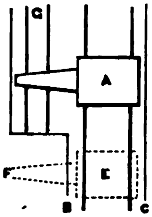
Cranes for lifting concrete blocks.

See page 787.

Far-reaching jibs.

Engineers in designing harbours or breakwaters, finding that no existing kind of apparatus will lift, convey, and deposit the heavy masses with which they have to deal, design cranes specially for their purpose, not only in regard to the main points of lifting and traversing the load, but also to secondary points, which are of scarcely less importance. Thus, the crane must be placed so as to be easily accessible to the loads brought to it, and to deliver them conveniently on the desired spot; and the crane itself must present as little obstruction as possible. The greater and more extended the work to be done, the greater the expenditure which is justifiable. For instance, in the

Special cranes for heavy loads.



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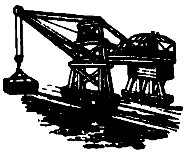
See VIGNETTE, *page* 116.



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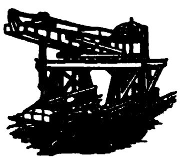

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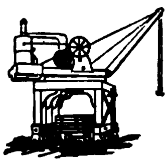


269.

construction of a harbour or breakwater, a movable crane for depositing heavy blocks of stone or concrete may be so arranged as to be clear of the road or railway by which the blocks are brought to it, so that wagons may pass freely under it while the load is being lifted, traversed, and lowered into place. Thus a breakwater or sea-wall having been first made wide enough B C for a single line of rails, a crane A (Figs. 266 and 267) moving on these rails may serve to lift concrete blocks brought within its reach either by water to the side of the structure, or by the railway G on the already widened part, and may then move forward to E to deposit them at F, so as to widen the structure along its whole length. Another form of crane (Fig. 268), equally powerful but more elaborate, is one of a hybrid kind, the lower part consisting of a travelling stage and the upper part of a movable crane which can traverse the whole width of the staging. A lifting machine of this kind is arranged for working at the end of a structure, building it forward into the sea; the wagons passing through from behind till the blocks they carry are within the grasp of the overhanging jib. The block of stone or concrete having been seized, the carriage on the jib from which the load is suspended is propelled forward, and the crane itself traversed across the stage till the block overhangs the desired spot, when it is lowered. It will be seen that these special cranes have only a rectangular motion, and are limited therefore to a particular range of duty. Jib-cranes revolving on a pivot or turntable, and mounted on a travelling stage (Fig. 269), while allowing the same unobstructed space below, can slew round in every direction, and are therefore suitable for more varied purposes. But in a jib-crane of this sort there is the disadvantage that the load cannot be racked in and out as in a foundry crane, and the alternative plan of raising and lowering the jib is often inconvenient. As, however, a short range of such racking movement is sufficient in most cases for adjusting a load, the slanting jib may be prolonged horizontally for a few feet, and a travelling carriage placed upon it as on the jib of a foundry crane. Huge machines of the kinds just described for lifting weights of 25 to 30 tons, and depositing them from a jib overhanging 30 to 50 ft., cost from £2000 to £4000.

Cost.

Floating-cranes.

Floating-cranes of considerable power are often required in harbours and docks for use in cases where it is more convenient to bring the crane to the ship than the ship to the crane. Strong vessels are needed to sustain such cranes, and while the stability depends primarily on the breadth of beam, the suspended loads are partly balanced by water-tanks or other counterpoise. A floating-crane with jib projecting 20 ft. beyond the side of the vessel on which it stands, and for lifting loads of 20 tons, will cost from £6000 to £8000. In some harbours where vessels of deep draught cannot lie alongside a wharf, floating-cranes or derricks are used for discharging cargo into lighters, but in such cases the cranes are usually of moderate power, and the peculiarity lies in the arrangement of numerous cranes on one hull as they might be on a wharf. Coals and similar bulk-cargo may be rapidly discharged from a ship to barges by numerous cranes fixed on a floating hull, and working simultaneously at two or more hatchways. A complete hydraulic equipment will generally prove best for rapid working. Grain in bulk is best lifted by "elevators," which have a series of buckets on an endless chain and ladder, something like a dredger; and, one end of the ladder being inserted in the hold, the buckets scoop up the grain and deposit it either on barges or into railway wagons on shore, or to the upper story of a warehouse. These elevators are sometimes fixed on a floating vessel and sometimes on shore, and they are as well suited for delivering into a ship as from it.

How used.

Grain elevators.

To allow a selection of a crane best suited to the purpose in view, or to enable an engineer or manufacturer to make an appropriate design, some or all of the following points need consideration, the importance of every incident increasing as the lifting power and radius required become greater :—

Choice of crane, how determined.

1. The average and maximum *Weight* of the articles to be lifted, and the relative frequency of each. If the maximun weight seldom occurs, it will be desirable, while providing the full power, to make the arrangements conform specially to the more frequent operations.

Power.

2. The *Size* or bulk of the pieces to be lifted. The shape of the jib has often to be modified and made of appropriate shape, this point having to be considered in connection with the length or projection of the jib; and on this the resisting power of the crane and the strength and cost of the whole apparatus often depend. In connection with this point it must also be considered whether the radius will have to admit of alteration, and the lifting power may be modified accordingly. Thus, a crane which will lift 12 tons at the extreme radius may be arranged so that it will lift 20 tons with a

Size and shape of pieces to be lifted.

Altering radius.

See page 798.

shortened jib. Directions as to the safe limits of loading should be conspicuously affixed to the crane, to prevent misuse and accident.

Frequency of working.

3. The nature of the operations to be performed and their *Frequency*, so far as will determine the expediency of steam-power and other arrangments for quick working. Any special circumstances, such as rapid working during limited hours of tide, should be considered.

Height of lift. *See page 795.*

4. The average and maximum *Height* of lift for which a winding-drum and chain must be provided.

Fuel. **Water power.** **Electric.**

5. If a *Steam-crane* is required, the kind of fuel should be described; if *Hydraulic* power, then the nature of the apparatus and pressure which is available; if electric power is already established, the system and the voltage, with which the crane motors must accord.

Foundations. *See page 131,* JETTIES.

6. If for permanent use in one place, a *Plan of the site* is useful in assisting the choice of kind and shape of crane. If a wharf-crane is required, the nature of the ground and its suitability for foundations should be described. If the crane is for an iron or timber jetty, a description or drawing of it should be furnished, so that the sufficiency of the structure to support the crane when loaded, or the method of strengthening it, may be considered.

7. If a crane on travelling-wheels is required, the width of the existing railway *Gauge*, and the width and height permitted for passage through bridges. But if rails are to be laid down specially for the crane, the limit of width within which the gauge may be made to suit the crane.

Ropes and chains. **Wire rope.**

8. In cranes of moderate power it should be stated whether hemp *Ropes*, iron *Chains*, or wire ropes are preferred, as the winding-drum as well as the sheave-blocks must be made accordingly. Hemp ropes are not suitable if exposed to the weather, and for any but moderate weights are cumbersome and inconvenient. Steel wire rope is now available as a substitute for chain or hemp rope, and offers the great advantage that it shows signs of deterioration, and is not, like a chain, liable to sudden fracture. But as wire ropes of various kinds and for various purposes are made, it is important that rope of sufficient flexibility should alone be employed. The manufacturer should be informed of the purpose for which it is required and the diameter of the barrel on which it is to wind.

[*See also* HARBOURS AND DOCKS: FACTORIES:
THE TRANSMISSION OF POWER.]

CHAPTER XXVIII.

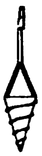
BORING-TOOLS. ROCK-DRILLS. DIAMOND-DRILLS. EXCAVATING MACHINES. DREDGERS. DIVING-APPARATUS. PILE-DRIVERS.

Boring-tools. *See* MINING, *page* 406.

For proving foundations.

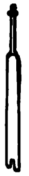
For bridge-piers *See page* 175.

Boring-tools, which find their principal use in prospecting for minerals and in sinking artesian wells, are useful also to the engineer or contractor for proving the nature of the ground for foundations. The latter may sometimes be sufficiently ascertained by digging trial-pits, and such pits dug on the banks of a river will generally prove the stratum likely to be met with in the river bed itself. But water in the pits generally hinders the excavation in this way, and for any but moderate depths boring-tools become necessary. In the construction of bridge-piers, of whatever kind, it is important that the nature of the foundations should be investigated before the form, dimensions, and depth of the piers can be determined. The firmness of the ground or the friction it would afford to piles screwed or driven down, may sometimes be sufficiently ascertained by driving iron-shod piles or iron bars into the ground and carefully recording the shape and size of such piles or rods, as well as the number and weight of blows by which they have been driven a certain depth. But information so obtained is inconclusive, and more elaborate plans are occasionally necessary. A sample from the bottom of a trial-pit, when water hinders further excavation, or from the river bed itself, may be obtained by a worm-auger of peculiar form screwed into the ground. The depth to which this plan is effectual depends on the cohesion of the soil. If the strata be of clay or gravel the worm-auger may be used for 6 or 8 ft., but the sides of the hole often fall in, and a fair sample can only be obtained by first driving a tube and screwing down the worm-auger inside it.



270.

For boring considerable depths, either in prospecting for minerals or in well-sinking, if the stratum to be pierced is approximately known, it may be possible to confine the choice of tools to those most suitable; but where the nature of the strata is uncertain, the boring apparatus must vary in kind, so as to pierce any stratum that may be encountered. For most kinds of ground, a boring-rod shaped like an auger (Fig. 271) is screwed into the earth, but when rock has to be pierced, cutting-chisels or "drills" (Figs. 272, 273) are driven by percussion. A tripod or sheers is placed over the bore-hole, and, by means of a rope passed round a pulley, the rods can be lifted by a windlass or steam-winch; and when rock or stony ground is met with, the process of "jumping" the hole is performed by lifting and letting fall the rods, the weight and percussive force becoming very considerable as the depth increases.



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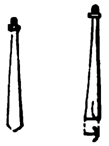
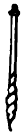


272. 273.
Chisel drills.

A usual method of commencing boring operations is to use first a worm-auger (Fig. 274) for penetrating the hard crust and for loosening the earth below, and then to substitute an open or "clay" auger (Fig. 271). A short length of pipe is sometimes driven into the hole at the commencement, so as to prevent the surface-earth falling in. The turning is done by means of tillers or handles fixed on the top length of rod and worked by two men as long as the process is easy, and then, by lengthening the handles, by four or more men, or by cattle or steam power. The rods are made in lengths of 10 or 20 ft., and a length is added as the tools descend. When the auger is full of earth or clay it, with the rods above it, is raised by means of the sheers and windlass, and the augers emptied. In deep boring, as the depth increases, the uncoupling of numerous lengths of rod each time that the augers are lifted becomes tedious, but some of this labour may be saved by erecting light but lofty sheers above the bore-hole, so that lengths of 40 ft. may be lifted at once. For longer lengths a light framework may be erected, or a tripod of poles lashed together at the top. Or if the first part of the excavation has been by digging, the boring-rods may be worked from the bottom of



274.
Boring-rods in 10 or 20 ft. lengths.

See Figs. 272 & 273

See also ROCK-DRILLS, *page* 816.

the well or pit, and the rods may be uncoupled only in long lengths. Thus if the pit be 50 ft. deep, the rods need only be divided into similar lengths. When it is desired to examine the stratification of the ground more exactly than the ordinary auger allows, an auger of peculiar form is used in which the earth or clay passes up intact as a solid core. If rock or stones are met with, and it is necessary to cut through them, a chisel-ended tool is substituted for the auger, and is "jumped" or driven against the rock by lifting the apparatus by the sheers and letting it fall, its own weight giving the necessary force. This plan becomes difficult at a great depth, as the rods vibrate and break the sides of the hole; the great weight requires considerable force to lift the rods at each blow, and tends to break the lower lengths. Boring-rods of this kind are partially turned at each blow, so as to make the hole circular.

Shell-augers.

Boring through pipes.

Deep boring at reduced diameter.

When the tool has passed through the rock, recourse may be again had to the auger, unless the ground has become wet or soft, when another tool, called the shell or pump-auger, which has a valve at its extreme end, is used, and this valve will retain silt or sand, or anything too soft to pass up the ordinary auger. When boring through running sand or other soft stratum, it is necessary to drive a pipe down the bore-hole to prevent the soil closing round and choking it. The pipe is passed down from the surface through the hard ground, and is then driven through the soft lower stratum, the pipe being cleared from time to time by a shell-auger. If hard stratum be again encountered, it is necessary to recommence with a tool of smaller diameter that will pass through the pipe. Hence, when deep borings are anticipated, it is important to commence with a large tool, as it may be necessary to reduce the diameter three or four times in a depth exceeding 1000 feet.

Grappling tools.

The tools above described are made of various sizes and shapes to meet the different occasions that arise, but besides the actual boring-tools and rods there are numerous secondary tools that become necessary. Thus there are grappling tools of various kinds and shapes, for seizing rods or pipes that become disconnected in the bore-hole, or stones that impede the augers; pincers, clamps, hooks and tubes. All these must be made of good tough iron or steel to withstand the rough usage and the oft-repeated strains that are unavoidable in boring operations.

Cost of boring-tools.

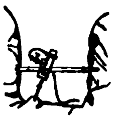
For testing ground down to 30 ft., the necessary tools can be purchased for about £15, but the expense increases with the depth of bore-hole, so that the tools cost about £100 for a bore of 300 ft. The deeper the hole, the greater the variety of strata likely to be met with, and therefore a corresponding number of tools must be provided. Moreover, if deep boring is anticipated, the hole must be made of large dimensions at the top, larger and more expensive augers and chisel-drills becoming necessary. The rods are square bars of iron or steel with screwed socket-joints; they are generally made in lengths of 10 ft. or 20 ft., and they must be strong in proportion to the depth of hole. Thus, 1-in. rods, costing about 23*s.* per 10-ft. length, are usually strong enough for holes 200 ft. deep; 1¼-in. rods, costing about 27*s.* per 10-ft. length, are needed for holes down to 400 ft.; while between 400 and 700 ft. 1½-in. rods, costing about 36*s.* per 10 ft., become necessary, and so on. For deep borings, or where rapid work is desired, a steam-engine is a necessary adjunct, though horse or cattle power may be substituted. Staging, sheds, and various other accessories have also to be provided, often at considerable expense.

Cost of rods.

Steam-power accessories.

Choice of tools, how determined.

A proper choice of boring-tools depends upon a full knowledge of the circumstances; and therefore the *Purpose*, the probable *Strata*, the anticipated *Depth*, the extent of the operations and the *Diameter* wanted at the bottom of the hole should be fully described to those concerned. The conditions under which boring operations are carried on are so varied, and the accidents that occur so peculiar, that experienced workmen are necessary for any but the simplest cases.



275.
Rock-drills.

Percussion Rock-drills are used in sinking shafts and driving galleries in mining and tunnelling, for boring the holes in which the explosives are placed. Drilling by hand, which was the only plan available till machine rock-drills were invented, is slow and laborious, and quite inadequate for large or speedy operations. The actual drilling-bit, or boring tool of the machine, resembles the hand-drill in being driven against the rock by a succession of blows, and in the partial turning of the bit between each blow, but the bits or boring-tools themselves are generally stronger, being made of various shapes from steel rolled for the purpose. While a hand-drill is limited to 8 or 10 comparatively feeble blows per minute, a machine-drill gives from 300 to 600 blows per minute, and each with great force according to the diameter of the cylinder and pressure available.

A machine-drill forms a complete steam-engine or compressed-air engine. There is a cylinder with piston, and to the piston-rod the drill is attached, so as to give a direct blow on the rock, a fresh length or piece of drill-bar being inserted, as in well-sinking with boring rods, as the hole advances. The blow is struck as by a chisel, and between each blow the drill turns partially, so as to render the cutting edges effective and to maintain a round hole. The drill is made to advance by a forward movement of the cylinders, controlled by the man in charge, but where several drills are mounted on one frame, as in tunnelling, the forward movement is automatic, because there is not room for a man at each drill, while one man can attend to several automatic drills. It is in these points, as well as in the kind of slide-valves or other mode of controlling the steam or compressed air, that the machines of different inventors differ.

Description.

Motive power.

Steam and compressed air are the motive powers generally employed for rock-drills because the elastic force is well suited to the sharp percussion required. Water has been used as a motive power, but the occasions when it can be obtained in sufficient quantity and force at the right place, without its exhaust or "tail" being in the way, are so rare that it hardly needs consideration. The direct use of steam is the cheapest, as there is necessarily loss of power when a steam-engine is applied to the intermediate purpose of compressing air, and there is again a loss when the compressed air gives out its force in the drill. Moreover, while only a steam-boiler is wanted in the one case, an engine and air-compressor are wanted in the other. For these reasons steam is preferred where, as in open quarries and railway cuttings, its use is practicable and convenient. But rock-drilling has in the majority of cases to be done in mines and tunnels so far from the open air, or in such confined spaces, that a boiler for generating steam becomes impossible, and even if steam be brought in pipes from the outside it is oppressive or unendurable. The modern system of using as power compressed air brought in pipes from a compressor at a distance, has therefore proved of great advantage, and is indeed more associated with rock-drilling than with any other operation. The manufacture of air-compressors for the purpose has become a specialty of trade. Even in open work compressed air is frequently employed where the apparatus has to be provided for tunnel work.

Steam.

See page 483.

Inconveniences of steam.

Compressed air.

See page 501.

Compression by water-power.

Where cheap water-power is available for turbines or wheels for compressing the air, the loss in transmutation may be of little consequence, and rock-drilling is then performed under the most favourable conditions, because, apart from the cost, air is preferable to steam. In regard to the transmission of steam from the boiler to the drill, there is always loss by condensation, the precautions for retaining the heat, which are usual and feasible in permanent situations, being inconvenient in temporary and movable apparatus; and the limit of distance is less than with air, which can, if necessary, be conveyed for several miles in pipes with little loss. Moreover, if steam be used, the machine and pipes become inconveniently hot, and the exhaust-steam is an annoyance. Compressed air is free from these objections, and has, as already described, the distinct advantage of cooling and ventilating the place where it is discharged, a circumstance of great value in mines and tunnels, especially where the air has been fouled by the explosion of gunpowder or dynamite. *See page 484.*

The leading dimension which determines the power and cost of the machine is the diameter of the cylinder; and as the size, strength, and weight of the parts are governed by this, the exigencies of portability and space, which render a moderate size and weight necessary, limit the power of the machine. The smallest machines are those made with cylinders of about 2 in. diameter, but these are used only for such purposes as splitting blocks and drilling plug-holes. The more usual sizes of machines range from those having cylinders 2½ in. diameter, with a piston-stroke of 3 to 5 in., and with a 16-in. length of feed, up to those with cylinders 4 in. diameter, 7 in. stroke, and 3 ft. length of feed. Machines of 5 in. and even 5½ in. diameter have been made and used sometimes for prospecting on exposed reefs, or for deep holes (30 ft. to 40 ft.) where the weight of the rods requires extra power, but they are unnecessary even for the most extensive tunnelling work.

Usual sizes of rock-drills.

Diameter of piston.

The kind and number of machines necesssary for any particular case depend mainly on the purpose and extent of the operations. Single small machines, though apparently effectual for a depth of two or three feet, are quite insufficient for speedy work, either in mining or tunnelling; and if, as often happens with inferior machines, they get out of order and cause delay, there is no advantage over hand jumping-drills. Rapid and continuous working without breaking, and the facility of adjustment, are the chief recommendations of a boring-machine. The action of a machine rock-drill is so severe as to suggest that it must knock itself to pieces, or irretrievably damage some of its parts; and too often this is the result, only to be postponed by slow working at moderate pressure. A strong, well-made machine, which will work effectually at moderate speed and pressure if

Choice of machines.

Machines liable to damage.

the available power be small or if applied to easy work, and yet which will, without damage, work at high pressure and speed if opportunities offer, is the one which is most remunerative in time and money. A machine-drill will work with a pressure of 20 lbs. per square in., but a pressure of 50 to 60 lbs. is best if the rock be hard and the machine well made. Generally it will be found that additional capital outlay to obtain the best apparatus is well repaid in a few weeks of working. Ample motive power should be provided, for although there may be periods of rest, during which steam may be generated, a machine when working to the best advantage demands a full and continuous supply. Even for small machines if worked directly by the steam, it is seldom advantageous to have a boiler of less than 6 horse-power, and this will suffice for two machines. When the drill is worked by compressed air, an engine of less than 10-horse power is seldom satisfactory. For each rock-drill employed, an additional expenditure of from £20 to £30 for air-tubing and drill-steel must be reckoned, but for tunnel work, when compressed air has to be brought a long distance, the cost of pipes is of course much larger. The proportionate power required for hard and soft rock occasionally varies with the depth of the hole, because there are some kinds of rock, such as sandstone, of which the chips and dust so choke the hole that, where long drills are needed, the aggregate friction more than equals the resistance of hard granite, although in the latter case the point and edges of the bit are blunted more. The limit of depth depends primarily on the power of the piston to lift the drill-rods in a vertical hole or to overcome the friction on the lower side in a horizontal hole. The maximum depth to which a machine rock-drill is effective is about 30 ft., but the great majority of drill-holes for explosives range from 3 to 6 ft. The depth of the hole not only increases the resistance, but diminishes the effective diameter of the hole or explosion-chamber; because, to enable the drills to clear themselves, the diameter of the hole at each successive length becomes less, the taper of a hole ranging from $\frac{1}{30}$ in. to $\frac{1}{10}$ in. per foot. Moreover if the hole be at an upward angle, the weight of long drill-rods diminishes the effect on the point, but, on the other hand, assists in clearing the drill in the backward stroke.

Range of pressure.

Ample power required.

See also page 782.
HAMMERS.

Boiler and engine.

Pipes and tubes.
See pages 644 *&* 654.

Limits of depth in boring.

Tapering holes.

As the ultimate purpose of a drill-hole is the fracture of the rock, the effective use of a machine depends not only on its capacity, but on the skill with which the holes, in their direction, diameter, and depth, are adapted to the kind and stratification of the rock, so that

Use of explosives.

In quarrying. *See also page 822.*

Diameter of hole.

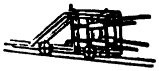
Explosion-chamber.

the explosive will split it most effectually. In this respect, the choice of method depends upon whether the mere removal of the rock is the object in view or whether the material itself is of value; and, as in the case of slate, marble, or building-stone, where pieces of certain shape and size are required, the holing and breaking must do the minimum of injury to the pieces. The diameters of ordinary blast-holes range from ¾ in. to 2 in., but they are seldom less than 1 in., except for plug-holes. The diameter depends, to a considerable extent, on the depth of the hole; first because, owing to the clearance space for the successive lengths of drill, the deeper the hole, the larger it must be at the outer end to allow of a taper towards the drill point; and secondly, because the deeper the hole, the larger is generally the mass to be moved, the greater the effort required, and therefore the larger the explosion-chamber. It is sometimes advantageous to explode first a small cartridge, which clears the hole and makes a chamber for the effective explosion. This method, however, is only suitable for certain kinds of rock.

Speed of drilling.

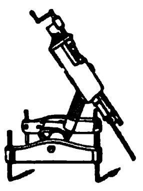
Cost of rock-drills.

It is impossible to state exactly the depth of hole which a rock-drill will make in a given time, as the variety of circumstances to be taken into account is obviously very great. Thus, while a good machine will drill as much as 6 in. per minute in hard rock, the adjustment of the machine as well as the withdrawal and renewal of the boring-bits occupies so much time that, even with such a machine, from 70 to 100 feet per day of ten hours, if maintained regularly with the same machine, may be considered satisfactory. The efficiency of a machine depends also on the kind and suitability of the accessories. For ordinary mining or prospecting, two 3-in. machines will generally suffice at each place of working, but for large tunnelling operations four or six 4-in. machines on one carriage become necessary if the full advantage of the process is to be obtained. The most rapid work in large tunnels can be carried on in a heading 7 ft. by 7 ft. A simple tripod stand is sufficient only for the easiest cases, and it is almost always advantageous to have stands or carriages which allow of easy adjustment in every direction, and yet which will remain steady under very severe work.



276.

A rock-drill with 3-in. cylinder costs about £50, and to this must be added the cost of the stand, the air or steam tubing, and a stock of drill bits. A tripod or stand of the simplest kind costs from £9 to £12, and weighs from 100 to 150 lbs.; but it is generally expedient to have a stand better adapted to various



277.

positions and steady under severe work; such stands costing from £30 to £60, and weighing from 100 to 250 lbs. A 10-horse-power steam-engine and air-compressor sufficient for two, or even for four machines, if not all working at once, will cost about £400, including boiler.

Cost of large apparatus.

For rock-drilling on a large scale much more elaborate machinery is required. A carriage with air-container, and having six rock-drills attached to it, so that it can advance on a line of rails against a tunnel face, costs from £500 to £700, and the air-compressing machinery and the numerous accessories would cost from £1000 upwards. A complete equipment for the largest tunnelling operations would cost from £3000 to £4000 if the full advantage of the machine process is to be obtained.

Steel for drills. *See page* 564.

Steel of the best kind for the bits, hard for cutting and yet easily welded, is essential to the profitable working of a machine-drill. Such steel costs from £40 to £60 per ton.

Hand-power machines.

Although rock-drills as above described are most profitably worked by steam or compressed air, hand-power machines have been introduced which are very effective where a motor is not available, and are particularly useful for mining prospectors. Such a small machine which is worked by two men can strike from 150 to 180 blows per minute, of from 150 to 200 lbs. force, nearly half as much as a 3-inch steam-machine. The percussive force is obtained in some of these machines by the recoil of a powerful spring, and in others by the rebound of air compressed in a cylinder. In either case the work is very trying to the men, and a double or treble set of men is necessary. These hand machines cost about £50 each.

Rock-drilling under water.

Rock-drilling is sometimes carried on under water. A machine fixed on a staging or boat can work through water as deep as 10 ft., but beyond this, the percussion of so great a length of drill without guides tends to break it, and it becomes necessary to place the drill near the place where it works. Rock-drills may be worked by a diver in helmet and dress, or from a diving-bell, and while one tube supplies the compressed air to the machine, another tube brings the exhaust-air to the surface, so as to avoid the back pressure on the piston if discharged into the bell. When the bell or caisson is in water not less than 50 ft deep, the machine-drill may with such an exhaust be worked by the compressed air in the bell.

By divers. *See page* 841.

The rock-drill has been used almost exclusively as a preliminary and accessory to explosion, which sometimes so breaks the rock or

Quarrying by rock-drills.

stone as to reduce the value of many of the pieces. Improvements have, however, been made by which the rock-drill, suitably mounted and controlled, may be traversed in a direct or curved line, so as to cut a chase or channel in the rock, and by mounting several drills on one carriage several channels can be cut at the same time. By this means a curved or angular block may be cut on the accessible sides and removed by the further aid of explosives. Rock-drills working in this way can cut a given amount of rock more rapidly than by holing, for in the latter case the successive blows in the same holes make a resisting pad of débris in front of the drill, while in traversing, the drill always strikes on the edge of the preceding blow and breaks away the rock more easily.

Cutting of channels or grooves.

Choice of rock-drill, how determined.

To allow a proper choice of apparatus for rock-drilling, some or all of the following information is required, according to the nature of the case.

Purpose.

1. The general *Purpose* and extent of the operation, whether in a quarry, tunnel, or mine; and some indication of the extent or rate of progress required.

Kind of rock.

2. The *Kind of rock* or stone to be drilled, its formation, and whether it is immediately accessible or covered with an upper stratum of other materials. If so covered, it is usual to dig a hole or sink a shaft so that the machine may be placed immediately on the rock. A drawing showing the mine-shafts, the section of the rock and the direction of the holes is useful.

3. If for quarry work, the *Diameter and depth* of holes required.

Steam or air power. *See page* 817.

4. Whether *Steam or compressed air* is to be used; whether boilers, engines, or compressors are required; or, if power is already provided, its kind and extent.

In conclusion, it may be said that no kind of rock-drill and carriage that has yet been invented is suitable for all circumstances, and that, to obtain the maximum effect, the whole apparatus must be adapted to the particular purpose in view. The importance of affording a full knowledge of the circumstances of the case to those concerned in the choice or manufacture of the drill is therefore evident.

See page 458.

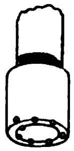
Diamond rock-drill.

The *Diamond Rock-drill* is used for sinking artesian or other wells, and for prospecting after minerals, and for hardly any other purpose; though occasionally it has been used for boring holes for explosives instead of the percussion rock-drill. For example, it has been used for the latter purpose in subaqueous rock-boring through

See page 816, ROCK-DRILL.

water about 14 ft. deep. Steel tools can pierce rock only by a succession of chisel blows; and as power rock-drills, which strike rapidly, are limited to a depth of about thirty feet, drilling through rock for greater depths is tedious and expensive. The piercing of rock by revolving drills is obviously a desirable plan, but steel, which suffices and may even be preferable for coal or other friable strata, is quite inadequate for the purpose, and the "jumping" of holes by chisel-drills was the only available plan till the invention of the diamond-drill, which will penetrate the hardest rock. Indeed, it will work more easily in a hard granite or hard siliceous sandstone than in some softer rocks. A hollow tube is used as the revolving spindle, and to the lower end of the tube is attached a ring or disc of larger diameter, known as the "crown," the face of which is studded, almost flush with the metal, with carbons or black diamonds which, when the crown revolves, cut, or abrade away an annular space into the rock. The solid core of rock passes into the tube as the drill descends, and by a simple arrangement the core can be secured from time to time, and brought to the surface in lengths of from 1 to 20 ft. While the drill revolves, a stream of water is forced down the tube at considerable pressure, for the double purpose of counteracting the friction heat of the cutting-faces, and of bringing up in the annular space outside the tube the powdered rock which the drill has cut away. Taking into account the expense of repairing steel percussion drills, the diamond-drill will do the same work as cheaply and at a greater rate of speed.

Revolving and jumping drills.



278.

Cutting crown.

Mode of working.

The diameter of the drill-hole depends on somewhat the same circumstances as in other kinds of boring, that is to say, on the diminutions that must occur from time to time during the descent. If there be hard strata throughout, the diameter need not be much reduced; for instance, a hole need only be 6 in. diameter at the top in order to be 3 in. diameter 500 feet below, this allowing for a core of about 1¼ in. diameter. Such a core obviously affords a better sample of the various strata than the small chips and dust obtained by a percussion drill. It is usual to line the bore-hole with tubes when passing through soft stratum, and allowance has to be made for these in determining the diameter of the hole. For prospecting, the smallest diameter that will work to the desired depth is all that is necessary, as a core of 2 in. diameter will tell the stratification almost as well as a larger one. But for well-sinking, where a tube for permanent service has to be inserted, diameters from 12 in. to

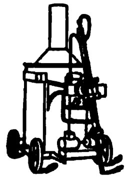
Diameter of drill-hole.

Bore-hole lined with tubes.

Solid core of rock obtained.

Deep drilling.

24 in. become necessary. A solid core, 20 in. diameter, of the hardest stone can be brought up from a depth of 1000 ft. and drilling can be carried on at a reduced diameter for more than 3000 ft. The rate of progress will range from 2 ft. per hour for depths down to 200 ft., diminishing to 1 ft. per hour at 1000 ft.



279.

Portable machine for prospecting.

A complete apparatus suitable for mine-prospecting, consisting of small steam machine and boiler, drilling-crown and diamonds, with drilling-rods sufficient for drilling 200 ft., costs from about £500, including 100 ft. of lining tubes and all necessary accessories. For a depth of 500 ft. the cost would be about £700. A small apparatus of this kind can be mounted on wheels and taken quickly to the desired place, set to work, and as quickly removed. The drill works most easily downwards, but can, if need be, work at any angle. A machine of this kind is portable and convenient for prospecting, but it is better in the case of large holes or deep boring to have a detached boiler, and lifting apparatus above the bore-hole for raising the rods. A derrick or sheers may be used for this purpose, but it is often advantageous to have a lofty framework, or staging of timber or angle-iron, which can be so made in lengths as to be packed in bundles for transport. A complete equipment of rock-drill, engine, boiler, tubes, rods, and accessories for depths down to 1500 ft. would cost from £1500 to £2000.

Cost of drilling.

Large holes for artesian wells.

Lining-tubes. *See page* 654.

The cost of rock boring depends on so great a variety of circumstances that no fixed rates can be stated, but where coal is obtainable at 30*s.* per ton, a prospecting machine as just described can be worked at a cost of from £3 to £4 per day, and with such a rate of expenditure the total cost will range from 8*s.* to 12*s.* per foot for depths down to 300 ft. In greater depths, such as the trial borings for proving the *strata* in the British coal measures, the cost has averaged about 15*s.* per ft. When large holes are bored, as for wells, tubular rods of from 6 in. to 18 in. (generally made of weldless drawn steel) are used; the cost of the apparatus rapidly increases, and for depths of from 1000 to 2000 ft., the cost of boring ranges from 20*s.* to 50*s.* per ft. The cost of lining-tubes will also range from 5*s.* to 40*s.* per foot, the cost increasing with the depth.

Ordinary tools used in conjunction.

Diamond-drills as just described will pierce the hardest known rocks, but sometimes it is expedient to use them in combination with ordinary boring-tools. Thus the latter may be used through soft upper strata or chalk; and if loose flints or nodules of ironstone are encountered, a jumping-drill will break them easier than the diamond

Difficulties.

drill, which is apt to loosen and turn them round rather than cut them. Various contingencies have to be provided for, as in all boring operations, and none but men accustomed to the incidents of boring can overcome the difficulties that may arise. Skill and experience are needed to ensure a straight vertical bore, as the drill may diverge considerably without any evident sign of it.

Weight and cost of diamonds.

Setting and re-setting.

The diamonds found most suitable for small prospecting drills, are from 1 to 3 carats in weight, and for larger drills from 3 to 6 carats (according to the size of crown and bore-hole). The black diamonds or "carbons" found in Brazil are the best for the purpose, and as the supply is limited, prices have fluctuated according to the demand, from £1 to £6 per carat during a period of a few years. When the price is high, Cape diamonds or "bort" are often used for drilling rocks of moderate hardness. About 12 diamonds are required in a crown of small diameter, and about 30 in the largest. Great care is required to set them firmly and in proper sequence, but if this be done they last a long time; and if occasionally reset, so as to obtain a new cutting edge, they will sometimes drill more than 500 ft.

Water supply.

Holes enlarged.

A supply of water is essential to drilling by diamonds, but when water is scarce it can be stored in pits and re-used. Although the drilling to a certain depth may be anticipated with certainty, the diameter of the hole at the finish can seldom be predicted. Bore-holes can be enlarged by rimering, the diamonds being specially arranged for the purpose; but this costs as much as drilling a new hole.

Excavating machinery.

Why used.

The use of machinery for Excavating earth, gravel, sand, and other material usually dug out by the spade, though often proposed by inventors, did not till about the year 1860 in America and 1870 in England, reach beyond experiment. Machine excavators and scoops had before then for many years been used for the sinking of wells, for bridge foundations and for subaqueous dredging, these being cases where manual labour in digging is difficult or impossible. The scarcity or high price of labour in some cases, and the great need for speedy execution of extensive works in others, drew the attention of contractors to new inventions which seemed likely to supersede or assist hand-labour; and even where none of these reasons would have sufficed, the saving in cost which the new machines were found under certain conditions to allow, ensured their adoption in the ordinary competition of trade.

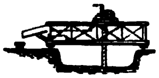
Different methods classified.

There are several kinds of machine excavators, but they may be broadly classed as of three kinds, i.e. those with a series of continuously moving buckets or scoops, as in a dredger; those in which one scoop or cutter is attached to an arm which forces it into the ground and digs out the soil; and those with hollow cutters or scoops which, being let down vertically, grasp the soil and bring it back as in a bucket. To these must be added apparatus for excavating by air or water pressure, and also boring-tools, the latter being principally used for well-sinking and prospecting for minerals, and are only employed for excavation as preliminary or accessory to larger operations. *See page* 814.

The experience gained with dredgers for subaqueous excavation where hand-digging is impossible, naturally led to the consideration of this form of machine when mechanical digging on dry land was required. So cheaply has subaqueous dredging been performed, and so skilful are the operators, that it has often been found profitable when a dredger-boat has been stranded at low water on a shoal or bank to continue working even although manual digging or other ordinary methods would have been possible. It appeared, therefore, a ready method to construct a complete dredging apparatus on a bridge or stage travelling upon wheels instead of on a floating vessel. The machines of this sort that have been made, resemble somewhat a travelling crane or gantry, moving forward upon a railway of from 30 ft. to 40 ft. gauge, and upon the bridge or transverse platform is a steam-engine and upper framework for carrying the "ladder" with moving buckets like those of a floating dredger. The ascending buckets are emptied at the top into a horizontal carrier, which discharges into wagons at the side. In a case of this sort the rail-track for the apparatus is on the ground-level, and the stage, spanning the excavated space below, works forward, the dredger buckets cutting into the solid wall in front as the machine advances. By this means a continuous cutting or gullet is excavated, which can afterwards be trimmed and widened by side-filling into wagons on a line of rails at the bottom of the cutting. An apparatus of this kind can be arranged in various ways to suit particular cases, according to the depth of cutting, the levels and other circumstances. In these respects there might be as many varieties as in a floating-dredger, but the facilities which the water affords for supporting the machine at the desired spot, for moving from place to place, and for conveying the spoil, are wanting in the land-dredger travelling upon rails.

See page 832.

Land-dredgers.

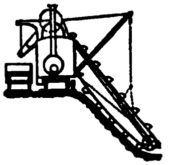


280.

Mode of working.

Not equal to floating-dredger.

Travelling land-dredgers can be made of a size small enough to move upon a railway of standard gauge, although when actually at work a third or outer rail is necessary for stability; the width of base so obtained determining the angle at which the buckets can work. In the cases where this plan has been applied, the arm or ladder is about 30 ft. long, sufficient for a cutting at an angle of 45° as deep as 15 ft. below the rail level. The buckets each hold about 6 cubic feet, and dig at a rate of about 20 buckets per minute. Machines of this kind are best suited for excavating sand or loose soil, or for loading up ballast into trucks. Much of the expense of working is in the continual moving back of the rails as the machine cuts away the edge of the bank.

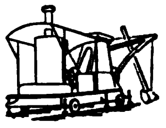


281.
Steam excavator on railway.

It is impossible to state the cost of excavating by travelling dredgers of the kinds just described, as so much depends on the subsidiary operations that have to be performed. When in full work, the saving over hand-labour may be undoubted, but the first cost of the machine, the expenses of fuel and attendance, the laying, maintaining, and relaying of the rail tracks, as well as the liability to delay from repairs, all add considerably to the outlay; and unless there be a very large amount of similar work to be done such as occurs sometimes in excavating docks, canals, and long railway cuttings, these incidental expenses are generally prohibitory. The occasions when the land-dredger can he employed with advantage are therefore very rare, but so various are the circumstances which occur in public works that experience gained with such apparatus may be utilised for modified methods when favourable conditions present themselves.

Land-dredger very rarely applicable.

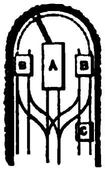
The Steam-digger or *Steam-navvy* has most of the functions of a crane to perform. The machine is fixed upon a travelling carriage, and besides the steam-engine, crane-post, and jib, there is a projecting arm with an iron scoop upon it which, by an ingenious combination of pulling, pushing, and lifting, cuts into the ground in front of it and scoops it away. To work effectively, the machine should be at the lower level of the excavation and cut upwards into the solid wall of earth in front of it. Starting from level ground against a slope or hill in front, the machine cuts its way, forming a channel or "gullet" as it proceeds. The width of the gullet is determined by the radius or sweep of the jib and the digging-arm, but it cannot cut at a steeper angle than 60°. A width of about 40 ft. has been found most useful, as it allows of a line of rails on each side of the machine, and, in the case of a railway-cutting, leaves only the trimming of the sides to be done by hand-labour.



282.

Steam-navvy.

Width of cutting.



283.

These machines may be worked with either two or three lines of rail, according to the arrangements for supplying and removing the trucks, the rate of working and other circumstances. But where, owing to the nature of the ground, the machine can work quickly, it is sometimes found expedient to lay three lines of rails. On the centre line (which must be of strongly laid rails to bear the weight), is the machine A, and, if need be, a line of empty trucks behind. The outer lines are about 3 ft. higher than the middle line, and serve for the trucks B, which are being filled, and for those C already filled waiting to be removed. Two men are generally employed to direct the machine; one man stands upon it, and, as in the case of a steam-crane, is able, by the various handles within his reach, to lift or lower the digging-arm or slew round the jib. The second man manages the scoop, which is made with a hinged lid or trap-door at the bottom, from which the spoil is discharged into the wagons. Besides these two principal men there is a fireman; and in addition there are men to trim the sides of the gullet, to manage the wagons and the lines of rail. But as these additional duties have also to be performed where the digging is by hand, they may be excluded in comparing the cost of actual excavation with that performed by hand-labour. The scoop has a sharp steel lip, and will cut into stiff clay, hard gravel, or chalk even when mixed with boulders. The scoop is first lowered into the position shown in Fig. 282, and cuts its way upward, and when it is clear of the surface and full of spoil the jib swings round like a crane, and the scoop, being brought over a wagon, is emptied by the opening downwards of the hinged bottom. The scoops vary in size, and hold, according to the nature of the ground, from one to two cubic yards; and according to the stiffness of the ground, the sufficiency of wagons and other accessories, the machine will excavate from 400 to 700 cubic yards per day, or about the work of 40 able men. The actual rate of work depends not only on the nature of the ground but on the efficiency of the arrangements for removing the spoil after it has been delivered by the machine.

Mode of working.

Rate of work, how determined.

Gullet widened by side-filling.

When the cutting or gullet has been made by the machine, the width of the cutting may be increased by side-filling into the wagons below. This course is convenient where the width of excavation required is greater than the machine can accomplish, and in excavations over a wide area, as in excavating a dock, a series of parallel gullets can be made, leaving only banks or ridges between to be cut away by hand and removed by side-filling. The machine

Excavation of docks.

can also work along a face, but has not then such scope as in a gullet.

A steam-digger as here described is made of steel and iron, except the digging-arm, which may be made of wood or iron. Although strength and rigidity in the digging-arm and in the gear which propels it are essential, some play or elasticity is necessary to prevent fracture when boulders or other obstructions are encountered. The engine is generally of about 10 horse-power; the weight of the machine (exclusive of fuel and water) ranges from 30 to 35 tons, and the cost from £1200 to £1400.

Cost, power, and weight of steam-navvy.

Machine and manual digging compared.

The expediency of adopting excavating machines of the kind just described depends principally on the alternative cost of manual labour in the locality, and the extent and nature of the work to be performed. When fully employed it has been proved by experiment that the steam-navvy will excavate at a saving of *2d.* to *3d.* per cubic yard as compared with manual labour. In the cost of the machine-process, interest on the purchase cost of the apparatus has of course to be reckoned, as well as the expense of repairs, deterioration, fuel, and the wages of the attendants; but accessories which are common both to machine and hand labour, such as the laying of the rail tracks and sidings, and the haulage of the full and empty wagons, may, as already stated, be excluded in comparing one with the other. The nature of the ground is, of course, a point of importance, for while sand, clay, alluvial soil, gravel, and even chalk are mastered by the machine; hard gravel, large or numerous boulders, or any stratum that depends on blasting, forbid the use of machine; while, on the other hand, if the ground be very soft, the maintenance of a track which will bear the weight of the machine may be so expensive as to be prohibitory. The desired depth of the cutting has also to be considered. If it is within the range of the machine at one or even at successive operations, it is much more profitably conducted than if a few feet in depth has afterwards to be dug out by hand. Some engineers have objected to the steam-diggers and other machine excavators because they disturb the ground more than hand digging, and because also the large masses of spoil they remove may not be so well suited for making solid embankments as is earth dug out by hand. On the other hand, the contractor looks mainly to the cost of the work, and is sometimes also inclined to use the machines even when little or no saving is apparent, because of the check they afford on the demands of the workmen.

Expenses.

Nature of the ground.

Too hard to cut.

Too soft to bear the machine.

Machine-dug soil not solid for embankment.

Machine a useful check on men.

Favourable occasions for machine-digging.

Inexpedient where labour is cheap.

Effects of climate.

Saving in time.

Machine excavators compare most favourably where the work to be done is of considerable extent, where skilled workmen for managing and repairing the machine are easily obtained, and where energetic contractors with sufficient capital have the control. Such opportunities occur, both on railway works and docks. For instance, the various kinds of machines here described were used in the making of the Albert Docks, London, and later for the Panama Canal and the Manchester Ship Canal. But in countries where there is abundance of cheap labour, as in India or China, but where skilled workmen are expensive and repairs or renewals are difficult of execution, these conditions tell greatly against the machine. In estimating the cost of manual labour, the rates of wages should not alone be reckoned, but the cost as measured by results. Climate and its effect on workmen have also to be considered. Thus, there are countries where, though labour may be cheap and abundant, the climate is so enervating that the workmen take frequent holidays, and works are much delayed. It may become expedient, therefore, to adopt machine processes to save time, even at a greater expenditure of money.

Subaqueous excavation. *See also* DREDGERS, *page* 832.

Pumping.

See DIVERS, *page* 841.

See page 842.

In the excavation of wells, mine-shafts, or pier-cylinders, so long as they are unobstructed by water, workmen can descend and dig out the spoil, which can then be hoisted in the ordinary way by buckets; and even if water be met with, it may often be kept back by pumping, so that the workmen can still descend; this, for instance, being generally possible in a clay stratum. But if the excavation has to proceed under water, mechanical means of some kind have to be adopted, and a great variety of methods have been tried to meet very different circumstances. If the ground be loose sand or mud, it may be pumped up, or a sand-pump may be worked by compressed air; and in the case of light clay or loam it may, if better methods are not available, be so stirred or loosened from above as also to be lifted by pumps. But as excavation or cylinder-sinking has generally to be continued till a firm foundation is reached, pumping hardly ever suffices alone. By means of divers, work can be carried on under water, and if the excavation be in cylinders or caissons which can be closed in at the top and made air-tight, pneumatic methods are available, but only within certain limits of depth.

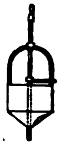
Mechanical digging ndispensable.

Beyond these limits, which range according to circumstances from 100 ft. to 130 ft., mechanical excavators which will act under water

Revolving cutters.

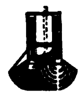
Spoil raised by syphon.

may become indispensable. Sometimes the excavation of the soil and the bringing it to the surface are performed by separate methods or apparatus. The method referred to above of loosening the soil so that it can be pumped up, has been elaborated in the sinking of pier-cylinders by the use of revolving ploughs or cutters worked from above to dig out the soil, which, when loosened, flows upwards through a syphon, a sufficient current of water being maintained in the syphon by pumping water into the cylinder, so that the water level there is always above that of the water outside. This method is costly, because of the engines, pumps, barges, and other apparatus required, but it may be used in mud or sandy soil for depths as great as 200 ft.



284.

Misers.

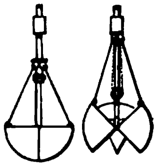


285.

Self-acting scoop.

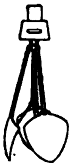
Self-acting buckets or scoops, for vertical action only, are made in a variety of ways, and great discrimination is needed to choose what is best suited to particular cases as they arise. Small circular boring-buckets or "misers" are useful sometimes in well-sinking, and can be employed for excavating in cylinders also. The most useful size is about 12 in.; they are made even up to 4 ft., but the latter are cumbrous in action and are not suitable for excavating considerable quantities. Buckets or scoops suspended from a chain are, if effectual, the most convenient kind, but as neither a thrusting nor a screwing motion can be transmitted through a chain, it is necessary that the scoop or bucket shall have a self-contained action. The scoops that have proved effectual, though of various kinds, are generally made of a segmental form, hinged, so that when descending they are open and ready to grasp the spoil, and when the hoisting commences can close and hold fast what has been grasped. In soft sand or mud the mere weight of the apparatus causes it to sink so far as to fill, and many of the scoops which have been used might be better described as self-filling machines than as excavators, and in this respect they may be used with advantage for hoisting grain out of barges; and, if open forks or grids be substituted for the complete bucket, will serve for hoisting coals.

Mode of working.



286.

To obtain a cutting action, it is endeavoured in the pivoting or hinging of the scoops to give such a direction to the cutting edge that when the hoisting-chain, by becoming taut, begins to pull the segments of the machine together, they cannot close without cutting downwards and grasping the spoil. But generally the tension of the hoisting chain has not been sufficient for this, and a second chain attached to the hinged parts has had to be pulled. By these means very effective work has been done in the excavation of pier-cylinders inaccessible to other kinds of apparatus, and the improvements suggested by experience in working have rendered them available even for dense clay, gravel, boulders, and other hard strata. In some of the scoops the closing by a separate chain has been much simplified and improved; while in others the separate chain is unnecessary, unless a very tenacious clay or hard gravel is met with, the buckets being made to close and grasp the spoil by means of self-acting cranks and levers. The largest of these scoops or grabs, as above described, will hold more than two cubic yards of spoil.



287.

Dredgers.

Dredgers (*dragues*). There is probably no engineering operation to which more numerous machines and methods have been applied than those for *Dredging*. Under this one term may be included the removal of any kind of material for the purpose of deepening a channel or harbour or dock, as well also as the operations necessary when the obtaining the "spoil" or material itself is the object in view. The circumstances are so varied that, unless full consideration is given to each case as it arises, the imitation of what has already proved successful elsewhere is likely to result in unnecessary cost or even failure. The simplest cases are those of removing material where it is only necessary to break up or loosen it so that the tide or current will carry it away. Generally, however, the lifting and transportation of the material have also to be undertaken, and considered as part of a general scheme.

Mode of working.

The "bag-and spoon" dredger, worked by manual labour from a small barge, is the rudimentary machine for scooping up mud or gravel, and it is still frequently employed for obtaining these materials for use as sand or ballast for concrete. The apparatus consists of a sheet-iron bucket or of a leathern bag, attached to a steel frame; it is guided by a long handle, and lifted by a small crane fixed on the boat. The characteristic feature which is associated with the name of dredger is, however, the ladder or rigid frame which is suspended from a floating vessel, and upon which works the endless chain of buckets which scoop out the ground as they pass round the bottom of the ladder, and deliver it as they pass round the top. The ladder is so hinged at its upper end that it may be raised or lowered to any angle, so as to bring the lowest bucket in contact with the ground at any depth within the range of the apparatus.

The following points, which must be taken in connection with

Design, how determined.

those enumerated on page 840, are those which generally determine the design of a ladder dredger.

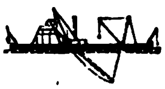
Depth of excavation.

1. The *Kind* of material, the *Depth* of excavation and the *Quantity* to be removed, are the main factors which form the basis of a design. A deep ladder needs a strong framing and boat to support it, and powerful machinery to work it, and the weight and cost of the apparatus increase accordingly. In dredging a channel in tidal waters, if continuous working is desired, the ladder must be long enough for the range of tide. Thus, if a channel 20 ft. deep at low water is required, and there is a 10 ft. range of tide, the ladder to be always effective must be long enough to dredge at 30 ft. But such a deep ladder may be avoided by working only within certain tidal limits. For mud or silt or loose sand the operation is little else but lifting (the friction of the machine, which is considerable, having also to be overcome); while for hard sand, clay, or gravel, the buckets as well as the machinery must be strong enough and have force enough to cut into the ground. For chalk, coral, or rock some or all of the buckets are made with teeth or claws that will force or cut their way and sufficiently break up the material to allow of its removal.

Range of tide.

Nature of the ground.

2. *The Nature of the operation* and the direction in which the work is to be carried on. Where a considerable area has to be excavated, or where there is a wide range of water in which the dredger may float, it may be immaterial from what part of the boat the buckets work, as the boat can move from place to place as the excavation proceeds, but if a channel has to be dredged between shoals or close up to a shore or quay-wall, the dredger ladder must be designed accordingly. Thus it can be placed in the centre of the boat, or two ladders, one on each side, may be used, or, the ladder may be made to project from either end. Such a dredger-boat may be so arranged that it can, while always afloat, cut away a shallow by the shore or even the shore itself above or below water. But in deciding on the position of the dredging-ladder the mode and direction of delivery must be considered.



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Delivery of the spoil.

3. The *Delivery* of the excavated spoil is usually into barges at the side of the dredgers, the full buckets as they turn over at the top of the ladder emptying into an inclined shoot, which discharges into the barge. If the ladder works in the centre of the boat, there may be shoots to each side, and by a simple arrangement, the spoil may be directed to the right or left hand to fill a barge on either side. Where the excavated material is of no value, and is merely

Deposited in deep water. dredged to deepen the channel, it is usual to discharge it into deep water in some place where it will not be inconvenient, or to utilise it for raising or reclaiming land by depositing it on shoals. **Or on to shore.** For discharging the spoil into deep water, what are known as hopper-barges are generally used for conveying the spoil, a false bottom or hopper allowing it to be discharged readily at the desired place. **Hopper-barges.** *See page 836.*

A powerful dredging-machine will keep employed numerous barges, and if the distance for transporting the spoil be considerable, **Steam-barges.** the barges may with advantage be propelled by steam, so as to bring them back to the dredger as soon as possible. Sometimes, however, the spoil is carried away in the dredger-boat itself, this plan being adopted for instance in tidal waters where the dredger can only work for a few hours each day, and when, therefore its steam-engine can **Hopper-dredger.** be utilised for propelling the boat. Such a hopper-dredger is arranged for discharging through a hopper or false bottom in the usual way, and can fill not only its own hold, but a barge also, **Compared with separate barges.** which it can tow. This plan saves considerable expense in barges, tug-steamers and labour, but against it has to be set the time which the dredger-boat is withdrawn from its primary duty. Such an arrangement does not add to the cost of the dredger so much as would be necessary for purchasing steam-barges, but the saving in wages or other expenditure must be carefully investigated before the outlay is justified. There is the disadvantage in using a dredger-boat in this way, that when it is brought back to work, time is expended in adjusting and mooring it to the face which it was operating against. A decision can only be arrived at in each case by duly estimating the distance, the times of working, the wages of the workmen, and other circumstances.

Dredged spoil sometimes valuable. In cases where the dredged material is of value, as in the case of river-sand for mixing mortar, or clay for bricks or Portland cement, it may have to be carried ashore; and in such cases it may be either removed by the spade and wheelbarrow, or by cranes and self-filling scoops, or by a land or floating dredger with buckets which discharge **Delivery on shore.** into wagons on the shore. The cost of conveying and depositing the spoil is generally as much as or more than that of dredging, and numerous plans have been tried to reduce the expense. Where silt or mud which can be kept in a semi-liquid condition has to be dealt with, it may be discharged by pneumatic pressure, specially contrived barges with air-tight chambers and steam-engines being employed. As by this means the spoil can be forced 500 ft. or more through a tube, the expenditure in fuel and wages for the steam-engine is in most cases less than that in wages for other methods. The plan of forcing through tubes may be adopted with advantage in reclaiming land in water too shallow for the barges to approach. In narrow rivers or canals the excavated spoil is often discharged on to the shore as it is brought up in the buckets, by long shoots or pipes from the dredger-boat, this plan being, for instance, often adopted in the dredging of irrigating-canals, and it was adopted in the construction of the Suez Canal, the channel being excavated and the banks formed by the one operation. Tubes as long as 100 ft. can be suspended from derricks or masts erected for the purpose; and where, owing to the level of the shore, an incline sufficient for gravitation cannot be obtained, the flow of the spoil can be assisted by pumps. Sometimes, instead of an overhead shoot, a syphon-pipe conveys the spoil under water on to the shore; in this case, as with the overhead shoot, the movement of the spoil being assisted by a copious flow of water supplied from a centrifugal pump.

Spoil forced through tubes.

Syphons.

Dredger-boats as above described are costly, and the service is so severe that expensive repairs and annoying delays can be avoided only by having every part of the best and strongest kind. The ladder is formed of wrought-iron or steel, and the links which hold the buckets are either forged from high-quality iron, or of iron bushed with steel, or are made as steel castings. The shape, size, and material of the buckets depend on the nature of the material to be excavated, but even for sand or mud it is usual to make the cutting lips of steel. To utilise a dredger-boat to the utmost, the steam-engine must be powerful and the connecting gear very strong.

Dredgers are costly.

Must be strong.

And powerful.

Dredger-boats are made at all prices between £3000 and £25,000. A boat 90 ft. long and 15 ft. wide, drawing 1½ ft. of water, with 10-horse-power engine and machinery for dredging 50 tons per hour from the bottom of a canal 6 ft. deep, would cost about £3000. A boat 80 ft. long and 20 ft. wide, drawing 4 ft. of water, with 25-horse-power engines for dredging 70 cubic yards per hour from the bottom of a harbour or river channel 25 ft. deep, would cost about £4000. A boat 120 ft. long, and 24 ft. wide, drawing 6 ft. of water, with engines of 40 horse-power, and capable of dredging from a depth of 25 ft. from 150 to 200 cubic yards of mud or sand per hour, would cost about £9000. A dredger-boat 120 ft. long by 33 ft. wide, drawing 5 ft. of water, with engines of 50 horse-

Cost of dredgers.

Ranges from £3000 to £25,000.

Examples.

power, capable of dredging 300 cubic yards per hour from a depth of 40 ft., would cost from £14,000 to £16,000. A dredger-boat 160 ft. long, 30 ft. wide, 10 ft. deep, with 70-horse-power engine, capable of dredging 400 to 500 yards per hour from any depth between 7 ft. and 32 ft., with propelling engines for a speed of 5 miles per hour, would cost about £24,000. A hopper-dredger, capable of dredging 300 cubic yards per hour, and with carrying capacity for 1000 tons, would cost about £25,000. Hopper-barges, equipped with propelling engines and other accessories, and capable of carrying 300 to 500 tons of spoil, cost from £500 to £9000. The exact cost of a dredger boat or barge depends not only on the current value of iron and other materials at a particular time, but on the kind and number of accessories and duplicate parts required.

Cost of barges.

Accessories and duplicate parts. *See pages* 451, 591, *&* 841.

Dredger-boats are so costly, and the expense and risk of navigating them across the sea are so great, that in foreign countries it is sometimes sought to economise by importing only the machinery, and to utilise an ordinary vessel for holding it. But this plan cannot be adopted with advantage, as the size, arrangement, and construction of the boat ought to be specially suited to the purpose in view. It is possible sometimes to build a suitable vessel in a place where the machinery itself cannot be made, but as iron or steel boats are generally preferred, it is seldom that they can be built except in places where the machinery also can be made. Sometimes, however, the dredger-boats are imported in pieces, and put together in the place where they are to be used, and in other cases the woodwork and internal fittings are made in the importing country. The cost of navigating a dredger-boat across the ocean is sometimes very great (from £1000 to £3000 has often to be paid, including insurance), as compared with the cost of freight when carried in pieces as cargo; but against any saving so effected, has to be set the cost and risk of putting the machinery together in a foreign country. Hopper-dredgers allow a saving in this respect, as they are large and strong and cost less for navigation than a dredger-boat and separate barges.

Ordinary vessels as dredgers. *See pages* 395 *&* 445.

Dredgers sent in pieces.

Or sent complete.

Cost of navigation. *See pages* 440 *&* 446.

Although the work of dredging has been greatly improved, and the cost reduced, there is always the disadvantage in the machines just described, that, owing to the friction of the bucket-links passing round the ladder, and the weight of the machinery to be moved, the effective work done as measured by the weight of spoil lifted to a certain height is only about one-third of the power employed. But

Friction of dredger machinery.

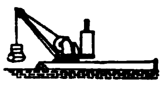
In proportion to results.

so cheap is the force which a modern high-pressure steam-engine can give out, that even with these disadvantages, sand, mud, or clay can be excavated and lifted very cheaply.

See page 838.

Various plans have, however, been tried of subaqueous dredging by other and simpler means.

A steam-crane, fixed in a floating barge, may be used for lifting self-acting scoops, and an apparatus of this sort (usually known in America as a dipper dredger), though perhaps not so suited as an ordinary ladder-dredger for long and continuous service, will do effective work with a much less capital outlay. The buckets may be made to hold any quantity between 10 and 40 cwt., and will dredge from a depth of 20 ft. from 200 to 700 tons of mud, or from 100 to 400 tons of clay per day, according to the size of scoop. A complete equipment of steam-crane with a radius of 18 ft., with scoops, chains, and other necessary accessories except the barges, costs from £500 to £1000, according to size. By this plan, excavation may be carried on in corners and narrow places inaccessible to an ordinary dredger. Sometimes the crane is fixed upon a wharf or jetty and discharges either into trucks on shore or into barges.



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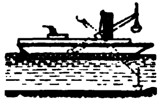
Scoops worked by steam-crane.

See page 831.



291.

This application of self-acting scoops to dredging has been attempted on a larger scale than that just described, and in vessels specially built for the purpose. The bucket is suspended from a rocking-beam so well balanced as to require in order to work it only a small proportion of the power necessary for the ladder buckets and other machinery of an ordinary dredger, and the suspended rod holding the bucket may be worked as a ram from a hydraulic cylinder so that the effective range of stroke may be extended. The rocking-beam is worked either by a steam-engine or by hydraulic power, and is so arranged that it can dredge at any level from 6 ft. above the water surface to 30 ft. below, as may be required. For mud or sand no power need be applied to the scoops except that of lifting, but for hard clay or ballast a hydraulic ram, as above referred to, attached to the end of the beam gives the necessary thrusting motion.

Self-acting scoops.

See page 831.

Worked by rocking-beam.

All the dredgers which have been here described have some moving machinery by which the material is grasped and lifted in buckets, but for soft mud or sand it is often sought to bring up the spoil in pipes without any such moving mechanism. This plan can be carried out either by water or air pressure. In the former case it is endeavoured so to stir up or loosen the sand or mud that a chain-pump, centrifugal-pump, or other pump not liable to be choked, will

Excavation by water or air pressure.

raise the spoil in a semi-liquid state. A jet of high-pressure air or water directed to the desired place is the means generally employed.

Pneumatic method. *See pages 496 & 843.*

There are various methods of applying air pressure. Thus, the soil may be forced upwards directly by the compressed air, either as presently described in the case of air caissons, or by means of a special apparatus of vacuum chambers and air-pumps, which maintain a vacuum in pipes pushed into the sand or soil to be excavated; a second pipe with compressed air or pressure-water scouring out the soil and assisting in forcing it up the vacuum pipe. The spoil can be propelled 500 ft. or more in the pipes if required. It will be seen that by this plan the spoil is really lifted up by pumping, the combination of vacuum on the one side to increase the effect of the air pressure on the other, being the peculiarity. By these plans of excavating, there is the advantage that much of the machinery and plant of an ordinary dredger-boat is avoided; and as the pipes occupy little space, they may be used in cylinders or caissons too cramped and confined to admit moving buckets, and also in narrow spaces and corners in harbours or docks. But there is the disadvantage that in lifting the spoil in a semi-liquid condition it is generally necessary to lift with it an equal or even greater quantity of water, the weight of which, of course, has to be deducted from the effective service of the motive power.

By air-pumps. *See page 496.*

Compared with ordinary dredger.

Cost of dredging.

The *Cost* of dredging varies within a very wide range, and the estimates put forward by inventors and advocates of particular systems, must be received with caution unless confirmed by actual offers from experienced contractors.

Special causes of expense.

Besides the obvious expenditure incident to the kind of material to be dredged, the depth of water and the distance of transportation, the circumstances of locality, time, and tide, as well as the limitation of season or weather, may go far to determine the actual outlay. Mud and sand have been removed at a cost of less than 2*d.* per ton, and from this price up to 8*d.* may be reckoned as sufficient for such materials, except in very exceptional cases. But for hard clay or ballast, or for uncertain and variable strata containing boulders or flints, or where there are contingent risks of encountering rocks, old timber or other difficulties, the price as measured by those who are willing to run the risk, will range from 9*d.* to 3*s.* per ton. Even this maximum may be exceeded where the cost of plant has to be divided over a small quantity of dredging in such awkward situations as

Obstructions.

pier cylinders or foundations. A trustworthy conclusion as to cost can only be arrived at after a considerable period of working, so that the real outlay for repairs and maintenance may be ascertained. Interest on capital must also be allowed for, and sometimes also a sinking fund to recoup the original outlay for special plant, whose use again within a reasonable time cannot be depended on.

Repairs and maintenance.

Modes of payment.

Dredging work is paid for in various ways. Where the circumstances are of a novel kind, contractors may be unwilling to take all the risks except at prices which appear inordinate, and it may prove fairer to all concerned to pay for the services of a complete dredging plant by the day or month, either at a fixed rate to include labour, fuel, superintendence, and maintenance, or at separate schedule rates for these different items.

By schedule rates.

See page 437.

Even where the above method of payment is adopted, specific operations of an ordinary kind, such as the transport of the spoil, may be scheduled at prices per ton or cubic yard; although there are certain risks attending the combination of day-work and piecework in one contract. In the majority of cases the whole of the work is done at schedule rates, per ton or per yard of material dealt with, and even where the contract is nominally for a lump sum, the latter is based only on approximate quantities subject to alteration or measurement which makes the schedule rates for work actually accomplished the real basis of price. When the agreed price is per ton or per yard of material gotten, there may be various rates either according to the kind of spoil or the depth of excavation or both. It is most satisfactory to all concerned when the excavated spoil can serve some useful purpose, and just as the material quarried from the side of a hill to enlarge a harbour may be tipped into the sea to form a mole or breakwater, so may the spoil dredged from the sea be used in the construction of an embankment or dock quay. Special ladder dredgers are contrived for lifting from the barges and depositing on an embankment, the spoil brought from the original dredger. Some of the apparatus used for this subsidiary purpose resembles that employed in and about the grain elevators used in Chicago and other ports of storage.

Carriage of spoil at per cubic yard.

See page 432.

Excavated spoil utilised.

Barges discharged by ladder dredgers.

When the main or only object of dredging is the deepening of a channel or dock or the removal of a bar, more cubic yards will have to be excavated than the gain in the sectional area of the water-way. For not only may there be much water in the spoil lifted, but the same causes by which the original shoal was formed may again

Net gain not equal to spoil removed.

operate and partially fill up the excavated space. The softer the material, the greater the allowance that must be made for such contingencies, and in the case of alluvial soil or mud deposited in docks or harbours by the regular action of the tide, constant dredging may be necessary.

Constant dredging necessary.

Choice of dredger, how determined.

In designing or selecting dredger plant for use in any particular case, the leading points which have to be considered, and on which full information should be supplied to those concerned, may be summarised as—

Purpose.

1. The *Purpose* to be effected; whether the removal of a bar, the deepening or widening of a river channel, the removal of banks or shoals, or the clearing of a dock.

Space available.

Delivery of spoil.

Soundings.

2. The *Space* available for the dredger, as in a wide or narrow river, harbour, or canal; and any particulars which may determine the direction of delivering the spoil from the buckets, whether into barges alongside, or at the end of the dredger-boat, or on to the shore. The above particulars may be given with advantage on a map, plan, or chart, on which also may be marked the soundings and the depth of excavation which is required.

Tide or current.

3. The *Tide*, or the range of flood level, and the strength of current.

Nature of ground.

4. The nature of the *Ground* to be excavated, and if varying according to depth, a section as nearly as may be of the strata; and if boulders, sunken trees, or other obstructions are likely to occur, their probable kind.

Period of working and amount of spoil.

5. The *Periods of working*; whether permanent or occasional, at tidal or other intervals, and the amount of excavation required in a given time.

Depositing of spoil.

Barges.

6. Particulars regarding the *Depositing* of the spoil in barges, whether in deep or shallow water, or on shore; the distance from the place of excavation; the mode of conveying the spoil, and the time occupied in transit; and any circumstances which may help to determine the kind of hopper-barges required, or the expediency of conveying the spoil in the dredger-boat itself.

Size of hull.

7. Whether *Living room* is to be provided on board the dredger, and if so, for how many men, and the storage space required for fuel, water, and provisions.

Depth and width

8. Particulars as to the length, width, and depth of water of any locks, dock-entrances, quays, or other spaces, with which the shape, dimensions, or draught of the boat must accord.

9. The kind of *Fuel* to be used, and its cost. **Fuel and water.**

10. The kind of *Water* available for the engine-boilers.

11. Whether the dredger-boat will be exposed to rough seas or winds, extremes of *Climate*, marine worms, and any particulars which will guide the choice of propelling power, anchors, cables, and other equipments. **Climate.**

12. Under whose *Management* the dredging operations will be carried on, and the kind of workmen and superintendents available for managing. **Management.**

13. The means of *Transport* to the site of operations, and whether the dredger-boat is to be navigated complete to its destination or sent in pieces. **Transport to site.**

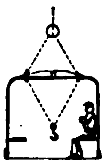
14. The facilities for *Repairs*, and such other particulars as will determine the number of duplicate parts required. **Duplicate parts.** *See page* 836.

Diving-apparatus, as used in engineering operations for enabling men to work under water, is of five principal kinds; the helmet and dress, the diving-bell, the air-lock bell, the air-cylinder, and the air-caisson. The main circumstance which limits the application of all these systems is the depth of water. A sunken vessel or other submerged object can be examined to a depth of 160 ft., but actual working can seldom be carried on below 120 ft. Portable electric lamps are now available under water, and a telephone in the diver's helmet greatly facilitates his operations. **Diving-apparatus classified.**

In the diving-helmet the air-supply must be of sufficient pressure to force open the escape-valve for the impure or already-breathed air against the head of water, and therefore the pressure from the air-pump must always slightly exceed that of the water, which is nearly ½ lb. per square inch for each foot of depth (43⅓ lbs. for 100 ft.) Improvements in the diving-helmet and dress have removed the risks which were unavoidable in the earlier and less perfect apparatus, and minimise the inconveniences of breathing under pressure, as the diver has now a ready means of controlling the air supply. It is found that no difficulty arises up to a depth of 50 ft.; that a diver after a little practice can as well descend 80 ft.; and beyond this, up to 150 ft., the depth at which work can be conveniently carried on depends on the constitution of the men. There are many divers who cannot descend more than 80 ft. There are few who can endure more than 100 ft., and 160 feet may be considered the maximum depth to which the strongest men will descend, **Helmet and dress.** **Air pressure.** **Water pressure.** *See page* 486. **Limits of depth.** **Ordinary and maximum depth.**

Cost of helmet apparatus.

although a few instances of endurance in a depth even of 200 ft. are recorded. Not only are the difficulties of breathing intensified at these great depths, but the pressure over the whole body becomes unendurable. The helmet, dress, air-pump, and other appurtenances forming a complete apparatus, as suitable for an engineer or contractor, costs from £100 to £120. The air-pump is the most expensive part of the apparatus, and as one set of pumps can, without proportionate extra expense, be made large enough for supplying two divers, a double equipment only costs about £150; but the pumps must be specially arranged for the purpose, to enable them to supply air at varying pressures, as of course the two divers will not be always exactly at the same depth. A light apparatus, such as is sometimes carried on board ship for examining the hull, and suitable for depths of 40 ft., can be purchased for about £60.



232.

Diving-bells.

Diving-bells (not now used so often as formerly) may be made either of cast or wrought iron, and if of the latter, there is a ledge outside on which to place kentledge or other weights which force the descent. A diving-bell of ordinary size is 6 ft. long, 4 ft. 6 in. wide, and 5 ft. 10 in. high. Round the inside of the bell is a seat high enough to keep the men's feet clear of the water. There are generally four lenses of thick glass on the roof; there are of course openings or inlets for the air-tube, and there is a relief or safety valve. There are usually four suspending chains attached to strong eye-bolts passing through the roof, and from these eye-bolts loads can be suspended and deposited as the diver may direct.

Air pressure.

Limits of depth.

Cost of diving-bell.

As a larger surface of water has to be held back, a more considerable escape from the mouth of the bell made good, and therefore a larger volume of pressure-air maintained than in a diving-helmet, larger pumps are necessary; but, on the other hand, the maximum pressure per inch which is required for divers in deep water does not occur in the bell, as the limit of depth within which men can safely work is much less. For while a man can endure on the small surface in the helmet where the air supply is guided and controlled, a pressure to overcome a head of water of from 80 to 150 ft., the pressure in a bell becomes oppressive beyond 50 ft., and 80 ft. may be taken as the greatest depth. Indeed, as diving-bells are generally employed for subaqueous structures, and not for the exploring and other miscellaneous work of a diver, the depth in the great majority of cases does not exceed 40 ft. A diving-bell complete with air-pumps and tubing, and with three tons of iron weights, costs about

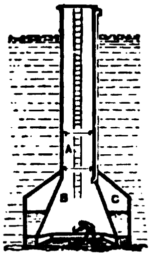
£200, but these prices do not include the cranes or any other lifting apparatus. The cost and inconvenience of lifting and moving diving-bells greatly limits their use; the diver in helmet and dress is generally preferable; and where an air chamber is necessary, the diving-bell has been superseded for many purposes by air-lock bells and air-caissons.

Air-lock bells.

Mode of working.

Buoyancy adjusted.

Air-lock bells resemble diving-bells in being open at the bottom and in having a working chamber filled with compressed air of force sufficient to hold back the water; but, unlike the ordinary diving-bell, they are always accessible from the top. The air-chamber B at the bottom is made of a size sufficient for the work to be done in it, and its height being limited to that convenient for the workmen, the space to be charged with air is of moderate extent. Above the air-chamber there is a cylinder or tube, large enough for men to pass through, reaching above the surface of the water and open to the atmosphere; and at the junction of this tube with the air-bell below, or, in some cases, at the top of the tube, is a lock or chamber A with a door and air-cock at each end, so that as communication is opened either with the compressed air below or with the atmosphere above, the men can pass in and out, and excavated materials can pass also. The air-bell may be lowered into its place by chains from above, but the lowering, raising, and moving from place to place, are rendered easy by means of the displacement in the working air-chamber, and also in other spaces C provided for the purpose above, which not only are equal to the weight of the bell itself and appurtenances, but to suspended loads also. On the other hand, the air-spaces can be filled with water, and ballast weights attached, so that the buoyancy can be adjusted and controlled.

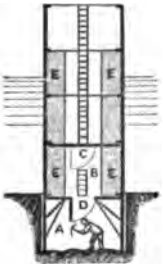


293.

Air-cylinders.

Bridge piers. *See* BRIDGES, *page* 140.

Air-cylinders somewhat resemble the bell as just described, as they are open to the atmosphere above, and have a working chamber below with an air-lock between, but they are generally permanent structures. That is to say, they are to serve as bridge piers, and when by means of excavation in the working chamber they have reached a firm foundation, the chamber is filled with concrete, the air-lock is removed, the entire cylinder also filled with concrete, or left as an iron column to support the bridge above. If a base larger than the column is wanted to afford sufficient bearing on the ground, the working chamber may be made of larger diameter than the upper part. Cylinders are generally forced down by weights, an ordinary plan being to place iron or stone on a timber framing on the upper tier. But by this plan a cylinder is apt to become top-heavy, and



294.

Cylinders of brickwork.

See pages 496 *&* 845.
SAND-PUMPS.

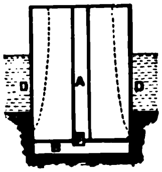
if the weights can be placed inside and low down, the sinking can be more safely effected. In such a case the lower tier may form a working chamber A, and the tier above an air-lock B, solid rings of brickwork or concrete E E being built up to give weight and stability. When the cylinder has penetrated to the desired depth, the air-doors C D may be removed, and the cylinder filled up solid with concrete. Or it may, in some cases, be possible to still further simplify the process by omitting the outer iron casing above the air-chamber, and, instead to build a cylinder of brickwork, the latter being built as on a floating caisson, course by course as the caisson sinks, an inner tube of iron allowing access to the air-chamber as in the air-lock bell. During the sinking of cylinders by the pneumatic system, if a very soft stratum be met with, the pumping may be reversed, a vacuum created, the material being forced into the cylinder by the atmospheric pressure, which at the same time, pressing on the outside of the cylinder, forces it downwards.

Cost of apparatus.

The pumps, air-doors, valves, and tubing suitable for an air-chamber 6 ft. high in a pier-cylinder 8 ft. diameter would cost about £300, and from this upwards there is a wide range, the power necessary in the pumps increasing rapidly with the volume of air to be supplied, and with the density or degree of compression as determined by the depth of water.

Air-caissons.

How made.



295.

The *Air-caisson* is an amplification of the air-cylinder, and is used where large foundations are needed. In this case, when the excavation is concluded, and the air-chamber B filled with concrete, a solid pier of concrete or masonry (as dotted) is built above it, and the tube A and air-lock F removed. The sides D D of the caisson may be of iron or timber, or both combined, temporarily strutted inside with timber during the building of the pier within; or if it be built of concrete, walls only of moderate strength would be needed, the space within being kept filled with water till the concrete displaced it, the pressure of the water inside balancing that without. The most notable examples of an air-caisson have occurred in the construction of the foundations of the St. Louis bridge over the Mississippi, where the air-chamber was 82 ft. long and 60 ft. wide; also at the bridge subsequently built over the East River at New York; for building the quay walls at Antwerp in 1882; on a still larger scale at the foundations of the Forth Bridge in Scotland in 1885–6; and in 1893–6 for the excavation of the Blackwall Tunnel.

The experience gained in the building of these foundations is of great value. It was found that healthy men could work safely at a depth of from 80 ft. to 90 ft., if only subjected to the pressure for about an hour at a time, and if the change to and from the compressed air chamber was made gradually. A depth of 100 ft. is the maximum to which the system of air-caissons can safely be reckoned on.

Limits of depth.

Advantage may be taken of the compressed air in cylinders and caissons to work machines. Thus sand or mud may be removed by means of a pipe from the air-chamber below open to the atmosphere above. The spoil being heaped round the lower mouth of the pipe and a cock opened, the air pressure will force the spoil upwards. Where rock has to be excavated, holes for explosives may be made by percussion rock-drills of the ordinary kind by means of the compressed air, if a tube from the exhaust orifice of the drill cylinder to the atmosphere above relieve the piston of back pressure. Of course where the compressed air is used for supplementary purposes of this kind, the air pumps must be equal to the extra demand.

Sand-pumps.

Rock-drills. *See page* 821.

In diving apparatus of all kinds it is of the utmost importance, for safety to the workmen, that the tubes, valves, and other parts should be of the best quality, kept in good order and tested periodically. The engineer or manufacturer to whom the design or choice of apparatus is entrusted should be fully informed of all the circumstances of the case, namely, of the purpose in view, of the other appliances with which the apparatus is to be combined, and of the depth of water.

Although considerable improvements have been made in the various pneumatic apparatuses just described, such systems are necessarily troublesome and expensive, and while the helmet and dress are cheap and available for a variety of purposes, air-cylinders and caissons should be used only when simpler methods are found to be too difficult or impracticable. The invention of automatic excavating machines which can be worked from above, are in many cases rendering the use of compressed air unnecessary.

Pneumatic method expensive.

See page 826.

Pile-drivers are worked either by hand or by steam-power, the latter giving ten times as many blows as is possible with hand labour and at much less expense. The falling ram of a pile engine is generally of some weight between 8 and 20 cwt., the latter being very rarely exceeded. For lighter rams, "ringing-engines" only are

Pile-drivers.

Ringing-engines.

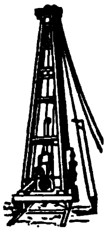
used, the weight being lifted by a hand-rope passing round a pulley.

Single power.
See page 794.

The winch of a hand-machine is worked by single power, whatever the weight, as double power would be too slow; the number of men being increased from two to five, according to the weight. Steam-machines are also worked by single power, so as to obtain speed; and it is inexpedient to increase the weight of ram beyond that which the steam-engine is arranged for, as the additional weight can only be met by increasing the steam pressure.

Suitability, how determined.

The suitability of a pile-driver depends not only on its action when working, but on various secondary points, such as portability, facility of adjustment and attachment. As pile-drivers have often to be pushed forward on a slight or overhanging stage, lightness is essential; and at the same time the apparatus must be stable enough to serve as a derrick for dragging and lifting the piles into position. The various automatic movements for catching and releasing the ram are now well understood, and are common to most pile-drivers, the more modern improvements being in the direction of portability, increased scope, driving diagonal as well as vertical piles, and such methods of construction as will allow of a pile being driven below the level of the stage on which the machine stands, without the interposition of a driving-piece or "dolly" between the falling ram and the pile head. Such machines are known as "telescope" pile-drivers.



256.

Telescope pile-driver.

Gauge-piles and wallings.
See VIGNETTE, *page* 813.

Where a continuous wall of piling is required, as for a cofferdam, it is usual to drive first separate "gauge-piles" at intervals of about 15 ft., arranging these very exactly in the desired line. These piles are then connected by horizontal walings, so as to form a guide or frame-work within which to drive the continuous or sheet piling. The last pile in each bay is made of special width, so as to fit tightly into

Key-piles.

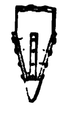
the space left for it, and as a key or wedge to squeeze all tightly and closely together. The proper driving of the piles greatly depends on the correctness of the preparatory work and on having the lower walings near the ground. Sometimes a ringing-engine or light machine

Advance work and staging.

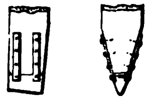
worked from a barge is used for driving the advance piles, on which can then be constructed a staging for a heavier machine; but even for advance work of this sort, steam-power can often be employed with but little additional weight, by detaching the engine from the machine and leading only the chain to it. But on a suitable staging or even a floating barge, the weight of the engine is an advantage as affording stability. Sometimes the engine is complete with boiler, but in other cases the steam is brought from a detached boiler, often from that of a portable engine.

Pile points.

The proper pointing of a pile has much to do with the correctness of the driving, for unless the point is true with the centre line of the pile, and the iron shoe also truly fixed, the pile is apt to go wrong. Gauge piles or staging piles should have diamond-shaped points (Fig. 297), that is, tapered square exactly the same on the four sides. Any unevenness in this respect causes the pile to diverge from a vertical line. But, for this reason, in sheet-piling the points are bevelled more on one side than on the other (Fig. 298), so as to cause the pile to press against the preceding pile, and so ensure a close wall.



297.



298.

Dimensions and prices of pile-drivers.

Pile-driving machines are generally made from 35 to 40 ft. high, and a manual machine has generally a base about 8 ft. square. Including one 15-cwt. ram, such a machine would cost from £50 to £60, or if, as is sometimes preferred for export, the woodwork be omitted, about £30 less. The usual height of a steam-machine is 40 ft., the base is from 8 ft. to 10 ft. square, and the weight when fully equipped is from 6 to 7 tons. Such a machine costs from £250 to £350, or about £50 less if the woodwork be omitted. Higher or stronger machines are occasionally made for very large piles, and also for driving iron piles. For any but large machines, it is usual to furnish the base with wheels, so that it can move along a line of rails laid for the purpose, a gauge of 7 ft. or 8 ft. being generally most suitable.

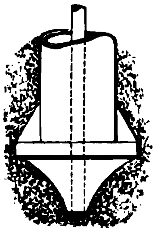
Weight and fall of ram.

See pages 761 & 780.

Discrimination is needed to determine the most suitable weight of ram and height of fall. Generally a heavy ram and moderate fall will do more effective work than the same aggregate force with a lighter ram and greater fall. On the other hand, the energy of a heavy ram may be expended in crushing the pile instead of forcing it downwards. The thickness of the pile, the kind of wood, and the nature of the ground are the principal points which determine the weight of the ram and its fall, but the depth of insertion, and the consequent friction to be overcome, have also to be considered, and for these reasons the ram is changed sometimes in the course of driving a single pile.

How determined.

Not only is it impossible to drive piles far into a hard stratum like gravel and chalk, but even sand or silt will, by its friction, offer a resistance when a certain depth is reached, which cannot be overcome by a falling weight. Where it is important that piles should reach a depth beyond that at which they might be "underscoured," the difficulty of sinking them may be overcome by attaching to the pile a tube through which water is forced with such pressure as to loosen the soil at the point of the pile and so allow the falling weight to take effect. A somewhat similar plan has been successfully applied to the insertion of hollow cast-iron piles into sea sand, the weight of the pile, assisted by a reciprocating circular motion, being sufficient to force it down, when the sand is kept in a "quick" or live condition by forcing water (as by a fire-engine pump) down to the point of the pile (Fig. 299) through an inner tube. When the pumping is stopped the sand will, in a short time, settle round the pile and grasp it firmly.



299.

Cost of driving piles.

Preparatory expenses.

Schedule rates. *See page* 437.

As much of the expense in pile-driving is in the cost of staging, of placing the machine, ringing and shoeing the piles and pitching them, the cost of driving would, if stated per foot, be more for a small depth to be driven than for a greater depth, as these preparatory expenses are about the same in any case. In any contract for pile-driving these circumstances must be taken into consideration, and if it be desired to arrange a schedule, then it is better to specify first a fixed price per pile and then a rate per foot. But even this is not enough if the strata be unknown or variable, as the cost of driving obviously increases as the pile becomes tighter in the ground, and a higher rate beyond a certain depth becomes necessary. An experienced contractor is, however, often able to meet all these contingencies by an average price, or is willing to take the risk for a certain sum of money.

[*See also* RAILWAYS: HARBOURS AND DOCKS: MINING ENTERPRISE: STEAM-ENGINES: CRANES.]

CHAPTER XXIX.

PORTLAND CEMENT.

PORTLAND cement was first introduced about 1840–50, and its manufacture has since attained enormous proportions in England and elsewhere. The name is misleading, for the cement is not made at Portland, but was so designated at its first introduction, because the concrete made with it had a supposed resemblance to the well-known Portland stone. When mixed with sand and made into mortar, Portland cement not only binds masonry or brickwork together with a strength and hardness unattainable in any other way, but, unlike ordinary lime mortar, it has the useful hydraulic quality of setting and remaining hard under water. It is, however, when made into Concrete or *Béton* that it has its highest value, and by its use as a substitute for masonry, and by the facilities it affords for subaqueous structures, cement-concrete may be said to have revolutionised this branch of the engineer's art.

Origin of name.

Strength and hardness.

The ease with which the materials for concrete may be brought to the site of building works, and there made into blocks of the desired form or weight, is an advantage which allows of building operations otherwise impossible. There is hardly any limit to the size of block that can be made, the difficulty arising only in the moving them. Cranes for lifting 30 tons are frequently provided on public works, but for heavier blocks special apparatus is contrived, or the blocks are floated to the place of deposit on rafts or pontoons. Besides this, homogeneous walls of any length can be moulded *in situ.* In docks and sea-walls, as well as in sanitary works of various kinds,

See HARBOURS, *pages* 116 & 122.

See CRANES, *page* 809.

wherever foundations have to be built under water or on wet soil, concrete or cement brickwork alone affords the necessary stability.

Quality and cost of cement, how determined.

The quality and cost of cement depend principally on the locality where it is made, on the kind of materials there available, and on the methods of manufacture adopted. The best Portland cement is made from a mixture of chalk (calcium carbonate), with certain kinds of clay (aluminium silicate), in proportions, speaking broadly, ranging from about 2 to 4 of chalk to 1 of clay, according to the kind of chalk and clay; and these materials (of which about two tons are needed for each ton of cement), having been thoroughly mixed, are calcined in a kiln and ground to powder.

Mixture of chalk and clay.

Cement making in London.

The principal Portland cement works in England are situated near London, on the rivers Thames and Medway, where there is a combination of advantages existing nowhere else in the world. The chalk and clay are found close together on or near the river bank, and yet quite separate, so that the proper proportions can be exactly measured; the coke from the large gas-works of London, also on the river bank, affords a cheap and plentiful supply of suitable fuel; and the situation of the factories allows the cement to be loaded into barges, coasting-vessels and export ships at a trifling expense. Moreover, as vessels leave London for almost all foreign ports, the cement as weight or ballast cargo has the advantage of low freights.

Coke fuel.

See COKE, *page* 536.

There are many variations of detail at all stages of manufacture. At first almost all the London cement was made by mixing the chalk and clay together in what is known as a wash-mill, in which they were stirred together with about an equal weight of water by revolving harrows, and by causing the mixture, when thoroughly amalgamated into a consistency like milk, to flow into shallow reservoirs or "backs," from which the surface water was gradually allowed to flow away or dry up, till there only remained at the bottom what is known among English makers as "slurry" or "slip," of about the consistency of butter. To still further dry the slurry by mere exposure to the air would, in the English climate, have taken too long a time, and artificial heat was employed; an ordinary plan being to lay the slurry on drying-floors near the kilns. These drying-floors were heated in various ways: in some cement works by ordinary fires; in others, where coke was made, by heat from the coking-ovens; while in some cases, the heat given off by the calcining kilns during the process of burning and cooling was utilised in connection with the drying-floors.

Method of manufacture.

Earlier methods by wash-mills and backs.

Drying floors.

Dried slurry calcined.

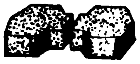
Clinker.

The slurry having been dried to a consistency approaching that of ordinary chalk (but still containing much moisture) was then broken into pieces and placed with about an equal bulk of coke in a kiln and calcined; this operation of burning and that of afterwards cooling occupying about three days. The resulting "clinker," as it is called, is intensely hard, and of a dark grey colour. The next process, after picking out and throwing aside all imperfectly burnt clinker, was to break it by rollers or by a stone-crushing machine into pieces about the size of a walnut; and it was then ground to powder between mill-stones. The above methods have, however, been considerably altered, as will presently be described.

Quality of Portland cement, how determined.

Mixed with sand. *See page* 857.

The quality of Portland cement and its fitness for the desired purpose are ascertained by various tests, and as there have been considerable changes in regard to these, as also in the methods adopted by manufacturers to meet them, the following particulars may be useful. The tests for tensile strength are by English engineers generally made with neat cement, but some engineers prefer to mix the cement with sand so that it may more directly represent the condition in which it has to serve in actual work. The elements of error in cement testing are, however, sufficiently numerous without adding that of the varying qualities of sand. A neat cement test for strength coupled with one for fineness ensures the desired quality. Standard sizes of test blocks have been established to allow of convenient comparison; the custom in England having been to use briquettes 1½ in. thick and 3 in. wide at the ends, reduced to 1½ in. wide at the middle, so as to give a sectional area of 2¼ square inches. Briquettes with a sectional area of exactly one square inch in the middle are also used, and since 1890 are adopted in the majority of cases. The briquette after being moulded is allowed to set for a certain time in a dry place, followed by a further period in water, and is then held at the ends and torn asunder, the fracture occurring in the middle as the weakest place.



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Test briquettes.

Density or weight of cement.

It has been found that it is impossible to rely on a cement being of an acceptable minimum strength unless it has a certain density or weight, and is ground to a certain fineness. The heavier the cement the harder it is, and the more expensive the grinding. Up till about 1880 the English standards of quality were accepted as sufficient throughout the world, and even the most important public works were carried out under specifications of which the following is an average example. The cement had to weigh not less than 112 lbs.

Grinding. per bushel (1·225 cubic feet), and be of such a fineness that it would pass through a sieve 40 by 40, equal to 1600 meshes per square inch, leaving a residue of not more than 10 per cent. Briquettes made of such cement were allowed to remain 24 hours in a dry place to set, and were placed in water for six days immediately following. **Setting of briquettes.** After this total period of seven days, the briquettes on being tested by tension were required to bear 300 lbs. per square inch without fracture. Much of the cement made under this specification was found to endure a much higher strain, and as the use of hydraulic mortar and concrete grew in quantity and importance, closer investigations were made to ascertain the real causes of these differences, and to establish a higher standard which could be relied on with certainty. These investigations originated in Germany, where, owing to the less favourable conditions in regard to materials, it was found that cement of proper strength could only be obtained by fine grinding. **Finer grinding demanded.** It was also found by English engineers and manufacturers that their cement could also be improved by the same means. Since that time sieves of 2500 holes to the square inch have been adopted, through which the cement has to pass without residue, and then through sieves of 5776 holes (76 x 76) to the square inch, **Sieves described.** leaving a residue of 10 per cent. Even finer grinding has in some cases been specified, but it must be borne in mind that fine grinding beyond a certain point is of no value. As regards the condition that the whole of the cement must pass through a sieve of 2500 holes, it is questionable whether an allowance ought not to be made for a **Residue after sieving.** certain residue so as to allow for a few coarse particles having passed the grinding mill.

Cement when made into mortar remains plastic only a few hours, **Quick setting of cement.** and its quick setting under water is useful for preventing the materials from separating or the cement from being washed away. But it is not desirable that cement should attain its maximum hardness in too short a time, as it is found that durability is best obtained by **Testing the period of setting.** slow setting. The time occupied in setting is measured by the resistance to the pressure of a blunt needle under a prescribed load, and also by repeating tensile tests at successive periods after the setting has commenced, so as to ascertain for how long a time the strength is increased by a greater hardness. Numerous opportunities of verifying the qualities of cement used under such conditions are afforded by the cutting away of old concrete or brickwork which has been set in cement. Unlike the testing of iron, brickwork, or other materials of construction demanding no preliminary treatment, cement requires much manipulation, and, at each of the numerous stages in the operation, a slight variation in treatment may involve wide differences of result, not caused by real differences of quality; and, therefore, while the testing of cement, properly performed, is of great value, it is dangerous to draw conclusions unless the circumstances are alike in all the cases which are compared. The making of the briquettes requires great care and experience, the quality of the briquettes being affected by the following circumstances. The freshness or age of the cement, the temperature, the quantity and quality of water with which it is mixed, the manner of moulding the briquette and of removing it from the mould, the temperature in which the setting takes place, the length of time in setting, the fact that it has set in or out of water, and also the skill displayed in getting the largest possible quantity of the gauged cement into the moulds in the shortest time. Even when the briquettes are made, the manner of holding them during the test, and the manner and rapidity of applying and measuring the weight, also help to determine the result; and erroneous conclusions are drawn if any part of the process is imperfectly performed.

Expert care in testing.

Growth of the cement trade.

The rapid growth of the demand for cement as its qualities became known throughout the world, and the even greater extension of cement factories not only in England, and the north of France, and elsewhere in Europe where chalk is obtainable, but also in Germany and the United States, where substitutes more or less suitable are available, led to a keen competition among makers. The great addition which packing for export and sea-freight make to the original cost of manufacture, naturally encouraged attempts to make cement in countries where it was to be used, but the absence of chalk has been a primary difficulty in almost all such attempts. Where chalk is wanting, limestone, sea-shells and other materials of a like nature are used. In the United States up to the year 1898, no marine chalk had been found available, but about one-fifth part of American cement was made from marl, having a large proportion (about 85 per cent.) of carbonate of lime or of chalk formed by decomposition of fresh-water shells. Most of the American cement is made from argillaceous limestone, which gives more or less the proportions necessary for cement, the exact proportions being adjusted by the addition of other materials. Cement so made cannot, however, be relied on to give a uniform

Germany and United States.

Substitutes for chalk.

good result equal to that obtained from cement of the proper Portland type.

The long period of settling in backs which was appropriate for clay mixed with chalk, is not suitable for limestone or other hard forms of lime used instead of chalk. In some such cases these hard materials are first burnt to render them friable enough to mix in a wash-mill. In other cases they are crushed and ground, and then mixed with a proper proportion of clay and enough water to render the mixture plastic. The mixture is then made into bricks which are burnt in a Hoffman or other usual kiln, and having thus attained the condition of "clinker" are broken and ground to the necessary fineness.

Semi-dry process.

Following partly on the above lines, but without the preliminary burning or hard grinding which is unnecessary in England, the semi-dry process has been adopted by the principal makers in the London district. That is to say, instead of the mixing in a wash-mill with water to about the amount of its own weight, which required a long period of settling in backs, the practice has become almost universal of mixing the chalk and clay with a minimum amount of water, and incorporating the whole by amalgamating between millstones while in this wet condition, and then evaporating the water from the slurry on drying-floors by artificial heat. After being burnt in a kiln the resulting clinker is crushed and pulverised by millstones, edge-runners, or other mills. **Blue lias cement.** In England and many other countries there are found numerous beds of lias and other marl in close combination or close contiguity with calcareous cement in which fossil fish shows the origin. Cement possessing hydraulic properties can be made from these materials, and is useful for mortar or concrete where carriage renders Portland cement expensive, but no cement made up to the year 1898 can equal in strength and durability that manufactured in the London district, if the comparison be made under the same condition of fine grinding which has been universally adopted by engineers.

Incidental to this minuter grinding, as fine cement weighs much less per striked bushel than coarse cement, it has been found advisable by some engineers not to stipulate for any weight according to bulk as formerly, but to specify instead, a certain specific gravity.

Use in public works.

For public works of importance, great care is exercised in testing the cement in accordance with elaborate specifications. But by

Elaborate precautions.

users who have not the means or apparatus for such precautions it will generally be found that London manufacturers of repute may be relied on to supply cement which will fulfil the conditions set forth in the specifications on pages 856–9. The trade marks or brands of such manufacturers are well known throughout the world.

Storage and treatment of cement.

Care is necessary in the storage and treatment of cement. It must be stored under cover, and should be protected from a damp atmosphere and from extremes of temperature. Cement is not fit for use until it has been exposed to the air for some time; and has been purged of any free lime which it may contain; and as the cement is sometimes packed and sent away from the factory directly it is ground, without sufficient exposure to the air, it should not be used immediately after taking it from the casks or sacks, but should be spread out on a dry floor, so that the air may reach it for a few days, and should, if possible, be turned over occasionally.

Range of prices in 30 years.

The price of Portland cement at English factories has ranged since 1870 from 21*s.* to 40*s.* per ton, exclusive of packing and transport. The expenses of packing bear a high proportion to the value of the cement. For carriage in the country of manufacture, it is usual to pack the cement in sacks holding about 2 cwt. But sacks, while sufficient for inland carriage, and even for short coasting voyages, afford insufficient protection in case of export and long-distance carriage, against rough handling in stowage or transhipment, and also against moisture.

Packing in sacks or casks.

Gross weight and net weight.

Casks holding from 300 to 448 lbs. are generally used; and by the custom of the trade, sales have been made per cask and not according to net weight; but, the tare being known, the net weight is the real measure of value. Casks add about 17*s.* per ton to the cost of cement, and it is seldom that the casks can be returned from abroad. Although this method of selling casks by their gross weight prevails largely among merchants, government engineers in England generally purchase only by net weight, 400 lbs. of cement being a usual quantity in one cask. In the absence of stipulations to the contrary, export casks are bound with ten wooden hoops and two iron hoops. As a safeguard against wet, a lining of waterproof paper is added, at a further expense of about 2*d.* As the cement, whether in sacks or casks, must be protected from moisture, carts, railway-wagons, or barges which are used for carriage must be covered.

It is only intended here briefly to indicate the methods of using

Use of cement mortar.

cement. Good mortar is made with about 2 parts of sand to 1 of cement; fresh-water sand being better than sea-sand. Concrete is made generally of shingle or gravel, mixed with cement of good English quality in such proportions that from 5 to 12 parts of gravel (which must include 2 parts of sand) go to 1 part of cement. The exact proportion within these wide limits must be determined by the importance of the service required, and the judgment of the engineer.

Making of concrete.

Although sand of a loamy kind will make a good lime mortar, the materials for cement mortar, if its full strength be desired, should be perfectly free from soil of any kind, and in order to ensure this they should be washed if necessary. Sharp and clean river shingle or coarse gravel affords the best materials, but coral, broken bricks, and many other materials are also suitable. slight porosity being an advantage. As the various materials employed in the making of concrete differ in specific gravity, and as the cement and sand form the matrix that holds the other materials, the proportions that determine the mixture are taken by bulk and not by weight. The quantity of water which may be added to a certain bulk of sand, without overflowing, will indicate the bulk or measure of cement which will fill up the interstices, and form a trustworthy matrix or mortar. The concrete should be mixed dry, and water applied and mixed immediately before depositing in place.

Depositing of concrete.

Where concrete is deposited in water, it may, with care, be lowered in open buckets, but it is advisable to pass such buckets through wooden shoots to prevent the concrete being separated, and where the current is strong, the concrete ought to be laid in place in canvas bags.

The following is the specification of quality on which the contracts of the London County Council were based in 1897.

London County Council specification.

The whole of the cement is to be highly-burnt pure Portland cement of the best quality, free from lime, slag, dust or other foreign material mixed with it after the cement has left the kiln. The cement, neat, must not set in less than one hour. It is to be ground so fine that the residue on a sieve of 5800 meshes to the square inch (equal to about 76 per lineal inch) shall not exceed 10 per cent. of the whole by weight.

Prescribed test.

The tests will be conducted by the officers of the Council at the Council's testing station, and those tendering shall convey to this place any samples of cement required free of charge.

Strength and fineness.

The cement, when tested neat, is to be mixed with about 17 to 20 per cent. of water, and shall then be capable of sustaining a tensile strain of 400 lbs. per square inch seven days after being made into briquettes, during the last six days of which the briquettes have been immersed in water. At the expiration of twenty-eight days the briquettes shall be capable of bearing a tensile strain of

550 lbs. per square inch, having been immersed in water during the last twenty-seven days.

Test with sand.

The cement, when tested with sand, is to be gauged with three times its weight of dry sand, which has passed through a sieve of 400, and been retained upon one of 900 meshes to the square inch. The cement and sand having been well mixed dry, about 10 per cent. of their weight of water is to be added, and briquettes formed in moulds of one inch sectional area at the weakest parts. The briquettes having in the meantime been kept in a damp atmosphere, are to be put into water twenty-four hours after they have been made, and shall remain in water twenty-seven days more, when their tensile strength is to be tested by the architect or engineer by means of apparatus belonging to the Council, and must bear without breaking, a weight of 200 lbs. per square inch.

The strain is to be applied in all cases at the rate of 200 lbs. per minute.

Chemical tests.

Besides these mechanical tests, the cement will be tested as to its chemical character, and as to its specific gravity, which is not to be less than 3·10, and if not found satisfactory in every respect, will be rejected.

British Admiralty tests.

The following specification is that on which the British Admiralty based their contracts for cement for export in 1897. It will be seen that very elaborate conditions are given in regard to packing.

1. The quantity of cement required is ...... tons. Delivery is to be made in one cargo within ...... weeks from date of acceptance of tender.

Conditions of delivery.

2. The cement is to be delivered into freight ship in the Thames, or in the Thames docks, as may be determined, in casks containing 400 lbs. net weight each. With each delivery the contractor must send to the officer in charge of works at ...... an invoice, stating the total net quantity delivered, number of casks, &c.

Casks must be kept dry.

The casks are to be kept covered and dry while in the lighters, and until they are shipped. The contractor is to be responsible for the care of the cement until it is delivered into ship. The casks will be retained by the Admiralty, and their cost, and that of the packing and delivery of the cement into ship, are to be borne by the contractor.

Penalty for delay.

3. Should the contractor fail to deliver the stipulated quantity of cement at the proper time, and of the proper quality, he shall pay as liquidated damages for non-delivery a sum not exceeding 1*s.* per ton per week for every week up to six weeks during which such cement remains not delivered. At the conclusion of the said six weeks the Admiralty shall be at liberty to cancel the unexecuted portion of the contract and obtain the cement elsewhere.

Verification of weight.

4. The net weight of the cement delivered on the works will be paid for. This weight will be ascertained by weighing 10 per cent. of the casks of cement as delivered, taken indiscriminately, and deducting the tare; on the net resulting weight per cask thus ascertained, the total net quantity of cement will be estimated and paid for, or the whole of the cement may be passed over a weighbridge, where one is available, at the option of the officer in charge of works. Casks damaged and palpably deficient will be set aside and dealt with separately.

Inspection during manufacture.

5. The cement will be tested on the contractor's premises by an officer or inspector, hereinafter called the inspector, appointed by the director of works, who will visit the contractor's premises and take samples of the cement for testing at such times and in such a manner as he may think fit. For this purpose

the inspector is to have free access to the contractor's premises at all reasonable times, and the contractor is to afford him every facility for inspection, and for taking samples and testing. He is also to provide free of charge and to the satisfaction of the inspector all apparatus required for testing the cement at the manufactory.

Storage in bulk.

6. All cement for this contract must be ground into a perfectly clean and empty bin or part of a warehouse properly partitioned off. Each parcel of cement offered must not exceed 250 tons, and if possible the depth of the heap in each bin should not exceed 5 feet. In cases where the maximum of 5 feet is not practicable, special arrangements must be made or appliances provided to enable the inspector to take a thoroughly representative sample from the heart of the mass.

Casks described.

7. The casks are to be made of sound well-seasoned fir, fully ½-inch thick and closely jointed; each case is to be bound with four strong new iron hoops splayed to fit the cask, and ten wooden hoops well driven on and firmly nailed. The bulge hoop is to be not less than 9 inches from the end of the staves. The heads are to be of fir or oak, not less than ½ inch thick, secured by two hoops each, one inside and the other out, the inside hoop to be not less than 1½ inches from the end of the staves; each head is to have cross bars not less than 3 inches by ½ inch. The points of all nails passing through the staves to be properly clenched. The casks are to be carefully lined throughout, including bottom and head, with strong pliable waterproof paper of a thickness to be approved by the inspector. All casks are to properly marked D ↑ W, and addressed to the officer in charge of works.

Cement must be of pure Portland type.

8. The cement is to be pure Portland, manufactured solely from chalk and clay of the best possible quality, and in every way suitable for use in engineering works of the heaviest character. It must be free from all admixture of Kentish rag, slag or any other diluting or adulterating material whatever, and the contractor must furnish to the officer in charge of works a certificate to this effect with each consignment.

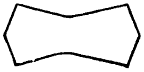
Time of setting.

9. The time of setting is not less than ten minutes, or more than three hours, and will be determined in the following manner. As soon as each briquette is gauged the time will be noted, and at frequent intervals a needle having a flat end $\frac{1}{16}$ of an inch square, and weighted to a total of 2½ lbs., will be applied to the surface of the cement. When the point of the needle fails to make any impression upon the surface the time will be again noted, and the difference between the second and first readings will be considered the time of setting for each pat or briquette; the mean of these times will be taken as the time of setting for the batch of cement to which the series of tests apply.

Fineness.

10. The whole of the cement is to pass through a sieve 50 by 50 = 2500 meshes per square inch, wires to be of brass and ·007 inch in diameter, while on a sieve 76 by 76 = 5776 meshes per square inch, made of brass wire ·005 inch in diameter, the residue must not exceed 15 per cent. by weight.

Tensile strength.



301.

11. The tensile strength is to be such that briquettes cast in the form shown on margin, giving to the briquette a minimum section of either 1 inch by 1 inch or 1½ inches by 1½ inches, as may be preferred, will sustain before breaking 350 lbs. on the square inch seven days after gauging. The strain upon the briquette will be applied at the rate of 100 lbs. in 15 seconds.

An average of the breaking strains of six briquettes will be taken as the strength of the cement.

The samples for testing will be taken from different parts of the parcel or bulk

Sampling.
See page 426.

in such a manner as the inspector may think fit. so that the cement tested may be thoroughly representative of the whole batch. After cooling, to the satisfaction of the inspector, the neat cement will be mixed with about 20 per cent. of water, or not more than is required to produce, when ready for the mould, a smooth, easily workable paste, that will leave the trowel in a compact mass. The gauged cement is then to be at once filled into the moulds, and all air bubbles thoroughly worked out. As soon as the briquettes are set they are to be removed from the moulds, and at the expiration of twenty-four hours from the time of gauging they are to be placed in water, where they are to remain until tested.

The percentage by weight of water used in gauging, the temperature of the water, of the testing-room, and the gauged cement to be recorded for reference.

Soundness of cement.

12. Pats of neat cement, 6 inches square and ⅜ of an inch thick, made on glass or other impervious substance, and placed under water as soon as set, and kept immersed for seven days, or if tested in any other way that may be considered necessary by the inspector to test the soundness of the cement, shall show no cracking, flying, or alteration of form. These pats of cement when broken are to show a section of uniform hardness and colour throughout.

Specific gravity.

13. The specific gravity of the cement when fresh burned and ground to be not less than 3·15, or 3·10 when it can be proved to the satisfaction of the inspector that some time has elapsed since grinding. Any cement of a less specific gravity than this minimum will be rejected.

Rejection of inferior cement.

14. A representative sample of cement from each burning will be submitted to chemical analysis if considered necessary by the director of works.

15. Should any of the samples of cement selected by the inspector for examination and testing by mechanical means be found in any way unsatisfactory, or not in accordance with the conditions of this specification, or should the result of the chemical analysis show that the cement contains more than 3 per cent. of magnesia, or that the composition of the cement generally is of an unsatisfactory character, or is likely to produce unsound work, the whole parcel of cement from which the samples are taken will be rejected.

16. No consignment of cement is to be despatched by the contractor without a written order to do so from the inspector. The contractor is to notify to the director of works whenever a parcel of cement is ready to be despatched from his premises.

Settlement of disputes.
See page 420.

17. Should any doubt arise as to the meaning of any part of this specification, or any difference arise with regard to matters of any kind relating to the carrying out of this contract between the officer in charge of works or inspector and the contractor, the matter in dispute is to be referred to the director of works, and his decision is to be final and binding on both sides.

In the year 1897–8 the cement works in the London district were manufacturing to their full capacity of about 25,000 tons weekly, and the works were being increased to meet the demand which was rapidly growing, notwithstanding the competition of many foreign countries.

[*See also* HARBOURS AND DOCKS : BRIDGES : CRANES.]

CHAPTER XXX.

IRON AND STEEL BUILDINGS. IRON AND STEEL ROOFS.

Iron and steel light and cheap.

IRON and steel are used in the construction of buildings and roofs for different reasons. First, in cases where they are better than wood because of their greater durability and strength, or better than stone and brick, because they occupy less space than these materials and can be more rapidly erected. Conservatories, winter-gardens, market-buildings, railway-stations, drill-halls, and race-stands are examples. Secondly, where the cost of transport has to be considered, iron and steel being lighter than other materials in proportion to strength. Thirdly, iron and steel are used for roofs and girders, because of the greater span they allow. Lastly, they are preferred for their cheapness, especially in the case of temporary houses, churches, warehouses, and other structures, which in most countries can be erected of iron and steel, at a less cost than of brick or stone, and sometimes even more cheaply than of wood. For buildings such as these, which might be more durable of brick or stone than of iron, the desire for cheapness may arise from the temporary purpose of the building. Even, however, where permanency can be reckoned on, the need for cheapness may outweigh all other considerations.

Easily erected.

Rolled iron and steel.
See pages 555 *and* 563.

The great development of iron buildings has been encouraged by the numerous forms of rolled iron and steel available to the constructor, of which not only ordinary T, L, and I sections are examples, but also those shown on pages 863–5, and by the strength and cheapness of corrugated sheet iron. Rolled joists or beams are more easily

Rolled beams.
See page 562.

produced than girders made of several pieces riveted together, and are useful for a variety of purposes, not only as parts of metallic structures, but for buildings in all other respects of brick or stone. Rolled joists are, however, not convenient for certain forms of attachment, and are sometimes misapplied, especially where the cheaper kinds are subjected to bending or smithing. For beams deeper than 15 inches riveted girders are generally to be preferred.

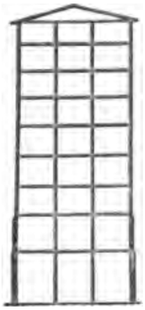
Ironwork only accessory to brickwork.

Steel floors.

In Europe, where masonry and brickwork are the usual materials for building, ironwork has generally served only a subordinate purpose, and has taken the leading place in a design only for such special structures as railway stations, markets, exhibition halls, and winter-gardens. In cities, however, where the land has grown in value, the saving in space which the use of iron allows has led to great changes. The most frequent use of iron and steel is for girders supporting floors, there being the combined advantages of an increase in the strength and span, a saving in the depth or thickness of the floor, and the facility by which, with such a metallic framing, a building made in all other respects of brickwork can be rendered fire-proof.

Steel structures in United States.

In the United States still greater progress has been made in the use of iron and steel. Timber is cheap there, and formerly the great majority of houses were framed of wood. Owing, on the one hand, to the frequency of fires, of which the conflagration in Chicago in 1871 and that of Boston in 1872 are notable instances, and on the other to the desire for lofty buildings, full use has been made of iron and steel, which can be composed and fitted at the manufactory and erected in a much shorter time than masonry or brickwork and without the liability to stoppage by frosty weather. Although the lofty buildings of twelve to twenty stories, as erected in American cities, have not been allowed in Europe, the skill shown in their design and the experience gained in their erection are available for structures of more moderate dimensions.



302.

Lofty buildings.

Foundations.

Timber piles.

Concrete bases.

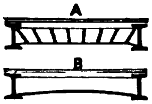
Masonry, brickwork, or terra-cotta have, in these high buildings, only a secondary place, the whole weight of the upper stories and floors being taken on a steel skeleton or framing. The solidity of the foundations for sustaining heavy loads is a primary consideration, and great ingenuity has been shown in building safely, even on weak or marshy soil. In the earlier steel buildings great expense was incurred in driving timber piles, but such piling has been reduced in importance or in some cases entirely superseded by the use of concrete covering the whole area of the site and held together into a homogeneous mass by embedding in it lines and cross lines of railway rails or rolled beams. This plan has in its turn been modified, because it was found that an equal strength of foundation was not appropriate for loads not everywhere alike, and by an unequal subsidence taking place in consequence. Footings of brickwork or concrete along the lines of walls are now often found sufficient, the width of the footings varying to suit the loads that are to be imposed, and to give a uniform pressure per square foot. Loads of from 2000 to 4000 lbs. per superficial foot are usual on such footings, while on strata as strong as "London clay" 10,000 lbs. per foot have been safely imposed. Not only are the main columns or stanchions, as well for the outer walls as for the interior supports, made of steel, but the horizontal members and bracings which complete the framing of the side walls are also so made. Rolled steel beams or riveted girders form the horizontal framework of each story, and the floors are generally made of hollow tiles or bricks shaped (A) to fit the beams, and which are incombustible. In England concrete (B), either flat or in arched forms, is generally used, because Portland cement for making the concrete is cheap and abundant. The concrete is made with ballast of small size frequently mixed with coke breeze, a combination which is strong, light, and proof against sound or fire. For steel buildings which have to be exported, concrete would generally be the best for the floors, as cement could be transported to the site more cheaply than hollow bricks unless the latter could be conveniently made at or near the site of the building. Both the English and the American plans have proved successful. There is a great variety of such hollow tiles, which are lightened and rendered porous by a slight admixture of sawdust with the clay before burning. Not only are the floors formed of fire-proof material, but the partition walls are made of it and columns are surrounded by it, so that the building is quite invulnerable to any fire except that caused by large quantities of combustible materials.

Footings.

Load per square foot.

London clay.
See page 171.

Hollow tile floors.



303.

Concrete floors.

The live load imposed on floors or platforms has to be provided for in a great variety of structures, and has been dealt with by engineers in all countries. The maximum allowed for in bridges ranges from 80 to 100 lbs. per square foot. The actual weight of people and furniture in rooms used as offices has been found in America seldom to exceed 10 lbs., and in order to provide a wide margin of safety, 75 lbs. is generally taken to include everything beyond the structure itself, namely, people, partitions, iron safes, and furniture.

Live load on floors.
See BRIDGES, *page* 149.

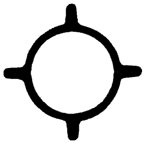
Weight of floors.

Cost per cubic foot.

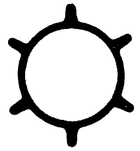
Strong floors for warehouses.

The dead weight of the floor for rooms 16 ft. square, including steel beams, hollow bricks, concrete, and thin wood surface, has been found to be also about 75 lbs., and this has been taken as a basis in calculating the total load of every story above the ground and first floors. For these lower floors 100 lbs. per square foot is a usual allowance. The weight and cost of the steel framework of office buildings as above described, and 15 to 20 stories high, has in practice ranged from $1\frac{5}{8}$ to 2 lbs. per cubic foot of the whole building, and the cost (excluding that of land) from 2½*d.* to 3*d.* per cubic foot, this being one-seventh to one-ninth of the total cost of the building fully equipped with heating, electric lifts and lighting, and all fixtures ready for tenants. It is of the utmost importance that the true purpose of a building should be known to the designer, because if merchandise or machinery have to be supported, the weight on each square foot of floor area may rapidly rise to 200 lbs. There is no difficulty in providing for such loads, or heavier ones, but the strength of the whole structure and its foundations must be increased accordingly.

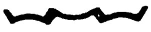
In England, about the year 1860, segmental bars (Figs. 304, 305) were riveted together as iron columns or screw-piles, and since that time the ribbed form so obtained has proved effective in giving stability to columns of moderate diameter and stiffening them against concussion. These same segmental bars were occasionally riveted together (Fig. 306) to form a stiff deck for railway bridges, the corrugated floor so obtained being in some cases strengthened by trussing-rods. This method has, however, been elaborated and superseded by a special kind of steel corrugated plates of fluted or trough shape. The wrought-iron segmental columns above described were, soon after their introduction in England, more extensively used in the United States under the name of the Phœnixville column, and were applied to vertical columns for the piers of bridges as well also as compression members in girders.



304.



305.



306.

Cast-iron columns.

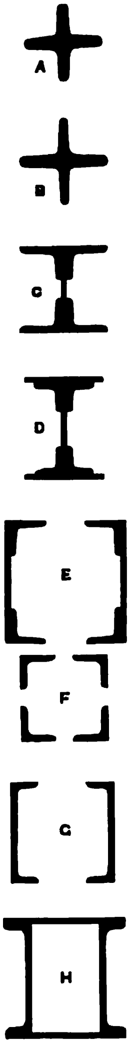
Strong against compression.

However, until about the year 1870 columns and stanchions were almost always made of cast iron, for three principal reasons: first, the cheapness of the material; secondly, the facility with which the desired shape—especially the cylindrical, which gives the greatest strength—may be obtained by casting the metal in a mould; and thirdly, the strength of cast iron under compressive loads. The belief (borne out by experience and experiments of recent years) that cast-iron columns resist the fire as well as or even better than those made of wrought iron, was an additional reason in their favour.

Architectural advantages.

Where architectural or highly ornamental forms are required, or where irregular shapes, projections, or connections are needed, cast iron may still be deemed the most convenient. The combined advantages it affords cannot, however, prevail against rolled steel (or even wrought iron) where the design is simple, and where the choice is determined by utilitarian reasons only. The strength of cast iron is not so great as either of these wrought materials, for although it has a greater resistance to direct or pure compression, the modulus of elasticity, which in columns is a matter of importance, is only half. Moreover a higher factor of safety is required in cast iron than in steel, to allow for the risk of faulty castings. Although rolled steel is only about 10 per cent. stronger than wrought iron when so applied, it is as cheap per ton, and it affords the great advantage of easier manipulation.

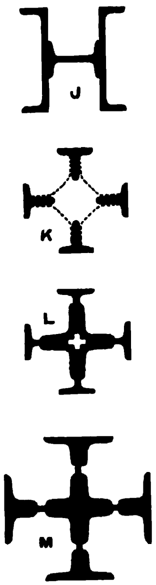
The modern introduction of cheap Bessemer steel, and the great advantages it affords in withstanding compressive as well as tensile stresses, revived and extended the use of segmental columns, and led the way to a much wider application of the same principle of struts and columns composed of bars riveted together. Figs. 307–318 (A to M) show some of the more usual forms. Commencing with the smaller sections, A and B, it will be seen that L bars or T bars riveted back to back form effective stanchions, not unlike those previously and still frequently made of cast iron. In these stanchions, although the steel is not disposed so economically for resisting the vertical and transverse stresses that may come upon them as are hollow cylindrical columns, they have the advantage of accessibility for painting, while a hollow column has its inner surface liable to waste by corrosion unless made perfectly air-tight by caulking or by being filled with concrete. More elaborate shapes become necessary when columns are required of considerable length or for sustaining heavy loads. The cylindrical form is not available in rolled iron or steel, except on a moderate scale. Tubes or pipes can be drawn, or welded or riveted, but there are limits to the thickness and diameter of such pipes, and they are not convenient for the attachment of bases, brackets, or capitals. These conveniences are, however, obtainable with more or less facility from all the forms shown here, where it is endeavoured to distribute the material symmetrically round a central axis. Sections C D H J resemble those common in horizontal girders, and in these trough or box shapes, as well as those of the X type (Figs. A and B), it will be seen that the separate bars



307–314.

Steel stanchions and columns.

are those which are commonly used for other structural purposes, and are therefore cheaply obtainable and easily riveted. Steel columns of this kind are rapidly superseding cast-iron in the construction of factories, foundries, ironworks, and other buildings liable to rough usage. Sections L and M are conveniently applied in the basements and lower floors of buildings for sustaining concentrated loads from girders or the brick walls of upper floors.



315-318.

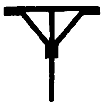
Steel columns.

When heavy or concentrated loads have to be sustained in cases where failure would be disastrous, these riveted steel columns are specially useful, and particularly also, where by contiguity to railway traffic or the movement of heavy merchandise, the structure may be exposed to concussions. Great ingenuity has been shown and experience gained in the designing of these riveted columns and stancheons both in Europe and America, and of their combination with girders and rolled beams to make complete metallic structures as referred to in the preceding pages. The various parts should be arranged so as to allow of machine riveting, and after the columns are riveted they should be faced in a lathe, or planing machine, so that when built into tiers they may abut properly and transmit fairly the loads imposed on them. The bed-plates, and any other parts that may interpose between the upper tiers and the foundations, should receive the same attention, and the fastenings should fit tightly. Without such precautions the advantages which these columns afford will be neutralised, and the structures of which they form part will, when subjected to moving loads, to wind pressure, or to expansion by fire, be liable to failure. The columns should either be encased in concrete or brickwork which will effectually shield them from the air and prevent oxidation, or, if the steel-work be exposed, it should be accessible for periodical scraping and painting. The liability to rust depends greatly on climate, and although it has not, in iron and steel structures, received all the attention it deserves, it has been incidentally met by the somewhat similar precautions for shielding steel structures from fire.

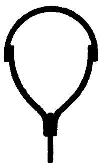
Protection from rust and fire.

See page 879.

Before leaving the question of riveted steel columns, it may be mentioned as analogous that the same principle of utilising an elastic material like wrought iron, in forms as near the cylindrical as possible, was recognised many years before the variety of rolled sections now available rendered its application possible. Thus, box sections were used in the Britannia tubular bridge; and, in the earlier railway



319.



320.

bridges, designed by Brunel about the years 1840–50, such shapes (Figs. 319, 320) were used in wrought iron as the compression members of girders, and many of these were still in use in 1898. These peculiar shapes were not, however, widely adopted, and the less symmetrical but the more easily constructed trough and box sections, composed of plates, angles and tees, have been preferred ever since.

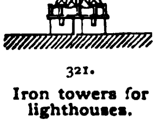
The strength and lightness which rolled steel affords has been well exemplified in its application to Lofty Towers, where the question of wind pressure is of greater importance than in the case of buildings having a base wide in proportion to their height. In such lofty structures the surface exposed to the wind can be minimised by leaving the steel skeleton-framing open. Even before the time when suitable steel was available, combinations of cast-iron columns with wrought-iron bracing had been successfully applied to lighthouses.

In all structures exposed to the wind and the waves it is best to avoid the shocks by exposing as little surface as possible to their direct action, and while in masonry towers this is done by having a smooth circular shaft with no angles or corners opposed to the wind and waves, in a tower made of steel columns the same result is attained, sometimes by adopting the shape of a masonry tower with a smooth outside of iron plates, but more often by having an open network through which the wind and waves can pass; stability being assured by the disposition of the supports, and the arrangement of the bracing; in this respect the principle followed for a lighthouse being similar to that in an iron landing-pier.

Open framework.

See LANDING-PIERS, *page* 127.

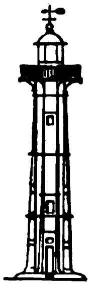
The numerous iron lighthouses that have been built may be divided into three principal types. The first is that resembling a stone tower by having its full diameter enclosed, this being sometimes adopted because of its supposed more pleasing appearance, or to afford space within for living rooms. It is, however, more expensive than other kinds, and is seldom adopted. The second type is that of a central shaft or column containing a spiral staircase, and round which are arranged a series of exterior columns of small diameter strongly attached to the central one at each tier by horizontal bracing, and continuously from top to bottom by diagonal bracing. Towers of this kind have in plan the form of a polygon, the diameter of which ranges from 10 ft. to 20 ft. according to the diameter of the lantern. Towers such as these, suitable for lights of the first three orders, would cost about £700 to £1000 if made 50 ft. high, and weigh about 40 tons for transport; from £1100 to



321.

Iron towers for lighthouses.

£1300 for a height of 60 ft., with a weight of 50 to 60 tons; from £1800 to £2000 for a height of 100 ft., with a weight of about 70 to 100 tons; and about £4000 for a tower 150 ft. high, with a weight of about 150 tons. But while these prices and weights may approximately represent what is necessary for the respective heights above the ground level, yet if, because of the loose nature of the ground, a wide base is necessary or screw-piles and other iron-work are required below, the weight and cost of the tower would then be increased according to the depth and extent of the foundations. The third type of iron tower (Fig. 322) is that of a central column with only three outer columns connected occasionally by horizontal bracing to the centre. Such towers, 40 ft. to 80 ft. high, cost from £5 to £10 per foot of height, the rate increasing with the height.



322.

Eiffel Tower, Paris.

Blackpool Tower.

New Brighton Tower. *See Vignette, page* 860.

Cost per ton.

The erection of the Eiffel Tower for the Paris Exhibition of 1889 was a new departure in iron and steel construction which has been followed by other buildings of a similar kind but on a smaller scale. The weight per foot of elevation in such buildings obviously increases with the height, as the load to be carried on the lower stages becomes greater, as also do the width of base and strength of the foundations. The metallic work in the Eiffel Tower, 1000 ft. high, with an extreme width at the base of 380 ft., weighed 5,200 tons for the framework of the tower proper, but the total weight including staircases, lifts, and other subsidiary work was 6,800 tons. The Blackpool tower, erected in 1894, is 500 ft. high, and the net weight of steel and iron was about 1,700 tons, or 2,400 tons in all. The New Brighton (Liverpool) tower, erected in 1897, is 520 ft. high, 114 ft. wide at the base, and weighs 1760 tons. The cost of such steel structures, when the price of steel bars and plates is £7 per ton, is about £15 per ton, to which must be added from £4 to £6 per ton for erection. There is no difficulty in designing stable buildings of this kind if a firm foundation of sufficient area is constructed, and the anchorage to it of the steel-work be suitably arranged. The cost of such foundation depends greatly on the nature of the ground, and according to such circumstances the outlay for it will have a proportion to that of the superstructure of from 15 to 30 per cent. There has also to be provided for the accessories of floors, pavilions, staircases, lifts, electric lighting, &c., a further addition of from 10 to 25 per cent. There is a risk of fire from wooden pavilions, but these structures should be too slight to burn long enough to heat the steel-work to a dangerous degree.

Iron roofs. *Iron Roofs* have to be considered separately, as their design is generally distinct from that of the building which they cover, and which, in many cases, is constructed of brickwork or masonry. As roofs have to span between walls or columns wide apart, lightness is of importance, and this was obtained by using timber till the stronger and lighter materials of iron and steel became available. Whatever be the form adopted—the arch pressing against abutments, the tied arch, or the truss, the ribs or chief members are known as roof "principals." **Roof principals.** On these rest the longitudinal beams or purlines, which in their turn support the local framework on which the covering material is laid, and to which it is attached.

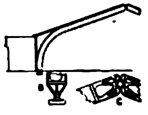
Where abutments cannot be conveniently provided and where it is desired to avoid tie-rods or trussing as unsightly, the arched from may be obtained by constructing the roof as a dome in which the thrust of the ribs is taken by a horizontal ring upon the walls, and if it be desired to have the centre of the roof raised for purposes of ventilation, the main ribs can be attached to an upper central ring which forms a horizontal tie like the lower and larger ring to which the ribs are attached at their springing. **Dome roofs.** Dome roofs as here described may be arranged on a rectangular, circular, elliptical or polygonal plan. The roof, elliptical in plan, over the Royal Albert Hall, London, is a notable example of a domed structure.

Roofs of large span. Roofs of large span exceeding 100 ft. need special designs, and some of the modern roofs over railway stations or exhibition halls afford conspicuous examples. Where the weight of such roofs is concentrated on lofty columns, care is necessary to avoid a clumsy or too heavy an appearance. **Precautions in using cast-iron columns.** The great strength against compression which cast-iron columns possess on account of their cylindrical section can be fully utilised only when the loading strain passes symmetrically through the axis of the column. Where the load is transmitted to the column by side brackets or where the load is imposed by girders or roofs of large span exposed to side movements by wind or changes of temperature, a column fixed solidly at top and bottom does not serve to the best advantage. It becomes necessary in such cases to increase the thickness of the metal or the diameter of the column, although it is not always right to increase the diameter because in some cases the strains are thereby increased. **Columns hinged at base.** In many notable structures built since 1870, great ingenuity has been displayed in bringing compressive stresses to a hinged point or pivot so as to ensure that the pressure shall pass through the axis.

Thus the ornamental columns supporting the bridges of the Metropolitan Railway, Berlin, are pivoted top and bottom A column so hinged may be said to resemble in some measure the slanting jib of a crane, the jib being so designed that whatever its angle from the perpendicular, the stresses caused by the load are passing fairly through it. In the Machinery Hall at the Paris Exhibition of 1889, the roof principals of 375 ft. span (Fig. 323), were pivoted (B) where they rested on the ground, and also (C) at the crown. Arched bridges offer an analogous example when, as is sometimes the case, they are similarly pivoted. The large spans of the Chicago Exhibition building were treated in this way. A still more complete articulation was effected in the Olympia building (Fig. 324), erected in London in 1884–6. Here cast-iron columns of moderate diameter could be safely used for carrying the concentrated loads of large arched roof principals, because the stresses passing through them converged at top and bottom to a ball-and-socket hinge (Fig. 325), while, in the absence of side walls or buttresses, artificial abutments had to be made of steel framing embedded in concrete below the floor.

As at Berlin.

As at Paris Exhibition.



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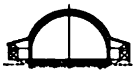
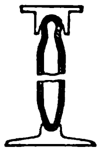


324.

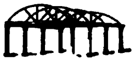
Olympia, London.



325.

Pivoted column.

Where an iron roof has to be fixed on a building of brick or stone, continuous side walls generally allow the roof framing to be arranged in the most advantageous manner without regard to the supports. But in an iron building the positions of the columns have first to be considered. Thus columns 8 ft. high may be placed as near together as 10 ft., for they may be made slender because numerous, and still be strong enough for the moderate height and weight. But columns 20 ft. high would have to be stronger, and therefore it is economical to place them farther apart, so as to load them with a greater share of roofing. In the first case (Fig. 326), a roof principal might be placed over each column, but in the second (Fig. 327), as the spacing of these principals is determined by other reasons than those by which the columns are spaced—namely, by the span, the system of principal, and the kind of covering material—economical construction may require that one or more principals be placed between each column, and to carry them, girders or arches must bridge the space between the columns. Sometimes a space as free as possible is wanted below, or numerous doors or windows, which hinder the placing of the columns; the latter may then be placed so far apart as to make the girders an important part of the building. Of course, the further apart the supports, the more care must there be to afford the requisite stability to those on which the loading is



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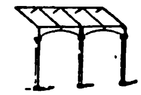

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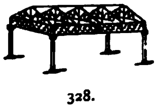

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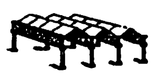

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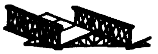


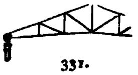
330.

Roofs on girders.

concentrated. In wide buildings where intermediate columns or walls are undesirable, roof principals of great span—which would have to be lofty—may be avoided by supporting the roof framing on long girders placed 30 ft. or 40 ft. apart, the roof principals being of these short spans.

Choice of roof, how determined. *See* BRIDGES, *pages* 136 & 174.

The choice between the many different kinds of roofs depends on almost as many and varied considerations as does the choice of bridges, the importance of choosing or making a suitable design increasing with the span. The main supports or principals are generally trusses or girders of some sort, and in most cases the trusses terminate in points of attachment to their supports, which may be columns, walls or girders. Where the trusses rest in this way on columns, the latter need some anchorage to the ground; but by giving a wider junction with the columns (Fig. 333) the structure is more independent of holding-down bolts. The loftiness of a building, its liability to strong winds or to unequal snow loads, assist in determining the design in regard to these points.



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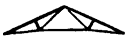

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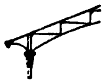

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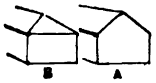
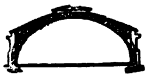


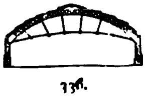
334.

A preference between forms equally appropriate in all other respects may depend upon the shape given to the ends of the building, gabled A or sloped B (hipped). Thus, what are known as English roofs (Fig. 331) generally allow of hip connections better than French roofs (Fig. 332). The angle of slope of the roof is determined not only by the depth and strength of the principals or girders, but by the kind of covering, the severity of the rainfall, the necessity of preventing leakage, and by the direction and force of the wind.



335.

Arched roofs.



336.

Tied arch.

Occasionally, strong walls, side buildings or galleries form abutments which favour the use of arched roofs, or the latter may be preferred even without these facilities for æsthetic reasons. Where there are no abutments, and an arched form without trussing is desired, the outward thrust may be withheld by a horizontal tie, or by allowing the arch to spring from the ground. In the first case the tie-rod is suspended from the arch by one or more light rods which have to sustain only the weight of the horizontal tie. In the roof over the terminal station of the Midland Railway in London, 240 feet span, the iron floor of the station serves as the tie. In the second case referred to above, the arches may be brought right down to the ground (Fig. 342) and attached to strong feet or bed-plates, this plan being suitable for buildings without galleries or upper floors. As iron and steel are specially suited to resist transverse strains, the strict rules by which stone arches are designed, and by which all possible

Stresses.

lines of pressure must be contained within the structure, may be disregarded, although, of course, the stresses must be met by sufficient material. By this means arched roofs which in effect spring from the ground, may be so designed as to afford a greater headway at the springing than a pure arch would allow.

Roof covering.

Double covering.

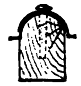
Air space between.

The disposition of the purlines and other subsidiary parts of roof framing is to some extent determined by the nature of the *Covering* material. Copper, zinc, lead, galvanised iron, wood, felt, tiles, slates and glass are all available, the choice depending mainly on climate and the desire for cheapness. In climates where extreme heat or cold has to be provided against, thick thatch is in many cases considered the best non-conductor, but in a modern iron roof, the same result is better obtained by a double covering, i.e. by an inner lining of boarding laid with an air space of about 3 inches between it and the outer covering.

Copper covering.

See COPPER, *page* 369.

Copper is the best metallic covering, for it is light, and, not being liable to rust, permanent. Roofing sheets weigh from 1 to 1¼ lb. per square foot, and vary in cost considerably, not only according to the current price of ingot copper, but, when laid in place, according to the amount of cutting and fitting required. The sheets are laid on boarding with wood rolls about 2 ft. apart, and as boarding requires supports every 2 ft. to 4 ft., the roof framing must be arranged accordingly. From 14*d*. to 18*d*. per square foot will include the general cost of copper roofing, including the woodwork and the cost of laying. The use of copper is encouraged when the metal is cheap, but even at its lowest price the expense is generally prohibitory. Notwithstanding its cost it is often advisable, even in buildings covered with cheaper materials, to use copper for the domes or pinnacles inconveniently situated for repairs and renewals.



337.

Covering for domes and pinnacles.

Zinc covering laid on rolls.

Zinc, when of pure quality, though not so durable as copper, lasts a long time, for although the surface oxidises it does not scale off, but forms a coating which protects the metal for a considerable period from further decay. Arranged with rolls like copper, the sheets may rest on the roof framing. It is, however, best, though not essential, to lay the rolls on continuous boarding. Zinc roofing sheets are generally of a thickness weighing about 1½ lb. per square foot, and the cost, when laid, is generally about half that of copper.

Lead covering.

Lead is the most durable of all metals for roof covering, but its weight and cost generally forbid its use on sloping roofs when other and cheaper materials are available. Lead has much less tensile strength than either copper or zinc. and the sheeting suitable for roofs should be of a thickness giving about 6 lbs. per square foot. Therefore, though it costs only about two-thirds the price per ton of zinc, it is dearer to use it, while the extreme ductility of lead renders a strong and close support of boarding necessary. Lead is most frequently applied for flat surfaces.

See LEAD, *page* 392.

Galvanised iron covering.
See page 552.

Galvanised iron, the name given to iron sheets coated with zinc, is, when corrugated, more used for roofs than any other metallic covering. The sheets will last as long as the zinc coating, this depending not only on the quality of the zinc (spelter) but also on that of the iron. Although good sheets will last a long time in pure air, yet in the vitiated atmosphere of large towns, or wherever they are subjected to gas fumes, even good galvanised sheets rapidly deteriorate, the durability then depending on the care and regularity with which they are painted. The great tensile strength of rolled iron sheets, and the stiffness which corrugation gives, allow their use for roof covering, without the support of boarding, the sheets serving also to brace the framework together. Indeed, small spaces up to 20 ft., or sometimes even 30 ft., are covered with corrugated sheets bent and tied at the eaves without any framework.

Preserved by painting.

B.W.G.
See page 551

The thickness of galvanised sheets is denoted by the number of the Birmingham wire gauge (B.W.G.), the thinner sheets having the higher numbers. Thus, corrugated sheets of No. 18 gauge weigh about 2·8 lbs. per square foot, No. 20 gauge 2·24 lbs. per foot, No. 22 gauge 1·85 lbs. per foot, and No. 24 gauge 1·5 lbs. per foot. In England it is customary to use, for good work, sheets of No. 18 or even No 16 B.W.G., but for export, sheets of Nos. 22, 24, and even 26 are more usual. In pure air these are long enduring if the quality be good, and full advantage may be taken of the great strength afforded even by thin iron when corrugated. But these thinner sheets are easily pierced, a surface crack or scratch of the zinc allows the commencement of rust, the crack grows into a serious rent and the sheets become worthless. But in regard to endurance against rust, good iron well galvanised will last longer than thicker sheets of inferior quality. In estimating the durability and cost of maintenance, it must be remembered that while copper, zinc and lead have, when worn out, a value as old material, old galvanised iron is valueless.

Destruction by rust.

Wood covering.

Except in wooden buildings, generally for temporary purposes, wood is seldom used as an outer covering, although, in dry cold climates, it is long enduring. Sometimes instead of boards the wood is cut into slabs or squares, known as *Shingles*, and laid so as to overlap in the manner of slating. But though wood alone can seldom be deemed permanent, it is invaluable as an inner lining, where it not only strengthens the roof, but increases its efficiency against heat, cold, rain and snow.

Shingles.

Hair felt, tarred, is very durable when well laid on boarding and sprinkled with sand; but it is not strong against abrasion, and is only used for temporary purposes because of its cheapness. It costs about 1*d*. per square foot. A peculiar kind of felted paper boarding is used in the same way. When an outer covering material of any kind is laid upon boarding, felt is extremely useful as an intermediate layer on which to bed the material, and it then serves to exclude damp and sound.

Felt covering.

Paper boarding.

Tiles are generally laid on boarding, and though seldom used as covering because of their weight, they are sometimes preferred on account of their pleasing colour or because they are better non-conductors of heat than slates or metallic sheeting. Where for the latter reason they are used in extreme climates, they can either be laid on boarding with or without felt between, or directly on L steel laths, with or without an inner covering of boards with an intermediate air space. Tiles are made lighter than formerly, and are ingeniously designed to lay and overlap properly. One thousand of such tiles weigh about 2¾ tons, and cost about £6, one "square" of roofing requiring 115 tiles.

Tile covering.

Where preferred.

Tiles on steel laths.

Slates are nearly as durable as tiles, with much less weight, and are probably more used in England for roof covering than all other materials put together, because they are obtainable in the country and transported at moderate cost. Roofing slates vary in size and thickness, those of large size being placed on wooden battens, and smaller ones on wooden laths, a close supporting framework being in either case necessary. When so laid, they afford little protection against heat or cold, and even when the joints are covered inside by mortar, the wind will often penetrate through the crevices. For these reasons it is best to lay the slates on boarding, and even to bed them on felt. In England, slating laid in place costs from £1 10*s*. to £2 per square, exclusive of boarding. In climates unsuitable to wood, the slates can be laid on steel laths as described above for tiles.

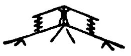
Slate covering.

How laid.

Cost of slating.

Ventilation has also to be considered, for if large openings are needed, shapes which would otherwise be suitable may need modi-

Ventilation.



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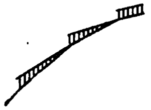
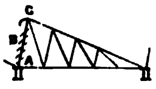


339.

fication. Ventilation is generally provided at the top of the roof by raised lanterns or domes, but openings in the purlines are sometimes convenient or necessary. Roof principals with curved or polygonal rafters are well suited to this arrangement. Openings may be also made under the eaves in the girders or spandrils which support the roof. Proper ventilation depends partly on the lower openings; and doors, windows or special air gratings may have to be provided at a low level to ensure an upward draught, while, as against extreme heat and cold, the double covering already mentioned for the roof, may be used for the walls also, the intermediate space being filled in with light concrete or other non-conducting material.

Lighting.



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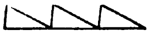
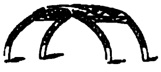


341.

Saw-shaped roofs.

The manner of *Lighting* depends mainly on the purpose of the building and on the climate. Certain manufacturing trades require the maximum of light, and sometimes, therefore, buildings are erected with a particular aspect, and with roofs of irregular form, a northern light being generally preferred. The long side of the roof may be covered without any glazing, and the steep side may be partly (A to B) lighted by glass louvre-blades easily fixed or replaced, and the upper part B C left open for ventilation, but shielded by a projecting hood. A series of such spans supported on girders, or on columns or walls and known as saw-shaped roofs, may be conveniently arranged in the roofing of a large factory, and the horizontal tie of each principal may be made sufficiently strong as a girder to carry lines of shafting. In large or lofty roofs accessibility for painting and repairs is an important point; for the expense of maintenance may be considerably reduced if convenient access is left for replacing broken glass or for painting. Unless roof structures are periodically examined and painted, they will rapidly deteriorate by rust, especially in a damp climate, or in places exposed to a vitiated atmosphere. A valley-gutter between each ridge forms a pathway. An iron ladder, curved or sloped to the profile of the roof, may be mounted on wheels to run on rails laid at the lower end on the walls or eave girders, and at the top on an upper purline, so that as the ladder travels along the roof it may give access to every part of the covering. The "ridge and furrow" system of roofing is convenient in the access it allows to every part of the covering. According to this plan, the purlines which rest on and connect the main ribs support a series of small roofs with slopes at right angles to that of the main roof.



342.

Glass covering.

When *Glass* is fixed on an iron roof by putty, the latter is apt to become hard and brittle and the glass being firmly attached is liable to crack when the framework of the roof expands or contracts under changes of temperature. The risk may be diminished by so mixing the putty that it remains soft, and also by using wooden sash bars. Another plan is to lay the glass without putty on zinc or lead sash bars, which are made to fold over the glass and keep out the wind and rain, while allowing the glass to slide sufficiently to prevent cracking. Such a system of glazing costs about 1*s*. per square foot, while ordinary putty glazing costs from 6*d*. to 9*d*. Accessibility for repairs, which is desirable for all kinds of roof covering, is especially necessary for thick or heavy glass. In many modern roofs of large span this point has been well considered; in others the neglect of it is a constant cause of expense and danger.

Putty glazing.

Glazing without putty.

Cost of glazing.

Glass has been cheapened by improvements in manufacture; large panes may be obtained without inordinate cost; and there is more variety in kind. For export to foreign countries the cost is greatly increased by the risks of breakage, and so excessive sometimes are the losses from this cause that twice the quantity needed according to the size of the roof has to be sent before sufficient arrives in safety. These losses arise for the most part from preventable causes. In the first place, the glass must be of good quality and well annealed; and only a moderate number of panes placed together in one wooden box. Two, or even three, small boxes of glass thus packed may then be enclosed in a larger case with padding of some sort. Cases or crates so arranged will withstand railway or sea carriage, if the cases are carefully handled and stowed. The panes of glass are arranged in the cases so that they stand edgewise, and breakages arise principally from the laying of cases so that the panes are horizontal, when they are not so able to withstand shocks, especially if the panes are of large size. In the transport of glass, the ordinary instructions to carriers are often insufficient, nor will bills of lading or marine insurance always cover breakage. Special precautions should be taken at each place of transfer or transhipment, to see that the cases are carefully handled and properly stowed.

Glass.

Breakage.

Packing glass for shipment.

Care in transit.

See page 447.

The harm which arises from undue economy in material depends a good deal on the care with which the structure is periodically painted. Wasting by rust necessarily tells sooner on thin than on thick iron. All parts of an iron structure should be accessible to the painter's brush, or else be protected from the air by being built into masonry, brickwork, concrete or cement. The protection obtainable by paint depends not only on its quality, but largely also on that of the

Painting of roofs.

See page 865.

Paint.

oil or other medium by which it is applied, as well also as the cleaning of the surface before painting, and especially at the periods of repainting. Sometimes cheapness is sought by using galvanised sheet-iron extremely thin, and if painting is neglected it soon decays.

Strength and value of roofs. While thickness and weight of parts afford one ready means of comparing the values of iron structures, the strength of a building depends also on the skilful disposition of the parts. As an iron roof is composed of numerous members, these must be arranged so as to **How determined.** resist and transmit the stresses in the most effectual manner; and if one member be weaker than another, the strength of the others will be of little avail. It has sometimes happened that roofs have been designed to sustain only vertical distributed loads, and if one-sided **Causes of failure.** pressure, as from wind or drifted snow, bear upon the roof, parts designed to resist tension only may become compressed and fail. The stability of a roof therefore depends a good deal on the **Wind-ties and bracing.** secondary parts, such as wind-ties and bracing, which only come into play under exceptional loadings or pressure. In other cases heavy chandeliers or other weights are suspended from roof principals never designed for such a service, or the roof is used for attaching chains and pulleys from which weighty articles are lifted as by a crane. An iron structure well designed in other respects may be defective in its connections, and the strength of its members rendered inoperative by the weakness or unskilful arrangement of the fastenings. **Connections.** The connections should obviously be able to transmit the same stresses as do the parts they join together. Screwed ends of rods should not be made so as to reduce the effective sectional area **Welds avoided.** of the rods. Welds and awkward forgings should be avoided, and full advantage be taken of the simple yet ingenious clips and attachments now available for rendering such methods unnecessary.

Use of steel in roofs. Although the use of Steel instead of Iron for roof framing seldom allows of a saving in cost till a span of 50 ft. is exceeded, the use of steel in some or all of the parts may, even for spans less than 50 ft., afford an extra strength beyond the extra cost. Steel may be used **Length of pieces.** *See page 561.* also to avoid unduly large and cumbrous pieces. Thus clips, shoes, and other parts of junction may be made of steel, or those where it is necessary or desirable to concentrate heavy loads or stresses. Apart from questions of strength, a principal reason for using steel in preference to iron is the greater length and weight of pieces which can be obtained at normal prices without extras. In short, steel is cheaper than iron. Steel is, however, hardly likely to be adopted so exclusively for roofs as for ships, bridges and boilers, for a roof is more often than a bridge composed of rods and pieces of moderate size which have to be smithed, and there is a preference in such cases for good wrought iron over steel by many engineers who fully accept the general advantages of steel. When a saving in weight is of great importance, as for distant carriage or to avoid import duties, high-quality material skilfully disposed will then repay an extra expenditure to obtain it. The importance of these considerations increases with the span and height of a roof or building, and especially if it be of peculiar or difficult shape.

Saving in weight.

Repetition of parts.

In a roof there is generally a great repetition of similar parts, and these should be made so exactly alike as to be interchangeable. A few spare or duplicate parts to allow for loss or breakage will then be available; while, if each piece will fit only into its own place the cost and trouble of erection are much increased. The quality of workmanship is specially discernible in the connections. Although all rivets should be perfectly tight, there are positions where bolts or pins need fit only with approximate accuracy; holding-down bolts, for instance, if they are well screwed down; and such looseness may even be necessary to allow of adjustment in erection. But there are other positions where tightness is of the utmost importance. There are places where holes must be drilled and bolts turned with great accuracy, in order to transmit properly the stresses passing through them; this care being especially necessary where more than one bolt is in the same connection. There may be more trouble in erecting a building with tight fastenings, but if the parts have been properly set out such trouble is well bestowed.

Good workmanship.

Drilled holes.

Tight fastenings.

Abutting surfaces planed.
See page 865.

Not only fastenings but surfaces must sometimes be fitted with great accuracy. Where iron comes in contact with stone or concrete, the inequalities of surface may be made good with lead, iron-cement, Portland cement, or bitumenised felt. Wood, if joined to iron, will adapt itself to the harder material; but iron and iron will not in certain positions fit properly unless the surfaces are faced in the lathe or planing-machine. This, for instance, is the case in a tier of columns for a building with upper floors. Machine processes are now so cheaply performed that the saving in first cost by the neglect of such precautions is only trifling.

Tiers of columns.

After all the conditions of stability have been satisfied, the value of an iron structure for any but the barest utilitarian purpose depends upon its style or finish. Much of the prejudice against the use of

Style and finish.

iron arises from inelegant design or from the coarse way in which it is carried out. An examination of the iron structures in a large city will show how great are the differences in this respect. In ornamental cast iron, for instance, the employment of an artist modeller to make the patterns may not add 1 per cent. to the cost, and yet afford a pleasing appearance which would otherwise be wanting. And in the processes of the iron foundry, skill and care are necessary to produce good castings. Again, in the foliage of a column capital, a good design may involve bold relief or "undercut," which requires care and expense in the manufacture. Too often such designs are carried out in a rude manner. Good patterns are the first essential, then suitable pig iron, and finally, capable moulders. Even where drawings and specifications are obeyed in all other respects, the close competition of manufacturers and the tendency to measure cheapness by price alone, lead to the employment for fine or difficult work of workmen accustomed only to rough or simple castings. Even the plain surface of a large casting or the tapering shaft of a column looks well or ill according to the skill in moulding, while column capitals or light spandrels afford more conspicuous opportunities for good workmanship.

Artist modellers.

Foundry work.

Neatness in finish.

In wrought iron and steel, as well as in cast iron, a good appearance depends upon the neatness with which the various plates and bars are joined together, edges planed or trimmed, and rivets hammered. The extra expense which such care involves may sometimes be saved in other directions by skill in design to avoid too numerous or costly shapes of iron, unnecessary smithing, and complications in the connections. Simplicity in these respects is generally best as well as cheapest.

Fire-proof buildings.

Fire-proof buildings, already alluded to, are generally made wholly or in part of iron or steel, but buildings so called often fail in practice. Misapprehension frequently arises from the different uses of the term. Iron and stone are fire-proof in the sense that they are uninflammable, but they are not proof against fire. That is to say, a building with walls of brick or stone, columns of iron, floors of hollow bricks or concrete arches on steel joists, and staircases of stone, will not itself be combustible. But such a building, if filled with combustible goods, or even with much wood furniture or fittings, or if surrounded by inflammable buildings, may fail if fire occurs. Few kinds of stone or marble will endure intense heat without crumbling away, and bricks

Stone and marble fail under heat.

of ordinary clay, while they will retain their strength at a greater heat than will iron, fuse or crumble under intense heat; though they will generally outlast a fire if the ironwork be protected Cast or wrought iron, subjected to the heat of boiling water 212° (Fahr.) loses 15 per cent. of its strength, and at the temperature of molten lead has hardly any strength at all. Wood, if of considerable thickness is under certain circumstances better than exposed iron to resist fire, because, though combustible, it is a bad conductor of heat and may retain part of its strength to the end, and may outlast the surrounding fire.

Combustible buildings.

This, however, does not imply that wood structures are more fire-proof than well-designed iron structures. A building cannot be properly designed to resist fire unless its purpose be known; and if, from the nature of its contents, a fire occurring inside would subject it to intense heat, then it must be constructed more or less like a furnace to resist it. One plan which minimises the effect of fire is to localise it by dividing a building into numerous rooms, separated by brick walls and iron doors strong enough to resist a fire in any one chamber till the combustibles are consumed, but this can only be effected by either avoiding iron columns altogether or by protecting them with some material which will resist great heat. Steel columns, of the kind shown on pages 864, 865, so encased will retain their strength and stability even though surrounded by fire.

Iron and steel encased.

In regard to the *Cost* of iron buildings and roofs, there are wide limits within which the price for a structure of given size may be varied according to strength and quality. This is the case to some extent even where competitive prices are based upon a common design with prescribed dimensions and thickness of parts; but in cases where merely the length, breadth and height are given by the purchaser and the details are left to the manufacturer, the range of possible difference is greater, and discrimination is needed to compare the real value of what is offered, or to decide which is really the cheapest. A large proportion of the iron buildings which are made, especially those for export, are for temporary use, or at any rate have cheapness as the first consideration; therefore a certain style of strength, workmanship and finish have become usual which are sufficient for the limited purpose in view. But such methods, which may be suitable for warehouse sheds or temporary houses, are quite inadequate for permanent structures like market buildings or

Cost of roofs and buildings.
See page 414.

How determined.

Temporary and permanent structures.

railway stations, and a comparison of prices, according to the area covered, between the two classes of buildings is fallacious.

Fluctuations in price.
See page 443.

Prices per square of 100 ft.

Iron roofs and buildings cannot be tabulated in regard to price, like machines or apparatus constantly alike, for it is seldom that the same circumstances combine more than once, or that exactly the same design can be repeated. Moreover, as the value of material has a much higher relation to the total cost than in the case of steam engines or machines, fluctuations in the selling price of iron or steel cause corresponding and continual fluctuations in the prices of the structures. It is sometimes attempted to value iron buildings according to their area, but for the above reasons prices so stated must be subject to considerable modification. The unit of size adopted in England is generally the "square" of 100 superficial feet, but as the strength and weight of roofs per foot increase with the span, the cost per square for roofs or buildings alike in other respects alters with the size. An increase in height must also obviously increase the cost; but if it be attempted to tabulate according to the volume or cubic contents, numerous circumstances render fixed rates inapplicable.

Prices by weight.
See pages 538–563.

It is, however, possible to separate the parts of iron structures so as to obtain a basis for estimating cost. First, in regard to weight: when pig-iron costs £2 per ton, iron columns and other cast-iron parts fitted for a building cost from £7 to £12 per ton; but if the design be complicated, or the parts very light or ornamental, these rates may be considerably increased. Steel joists cost from £8 to £10 per ton, and wrought-iron or steel parts, such as girders, from £12 to £18 per ton at a time when iron and steel are selling at £8 per ton, and lighter parts, as in roof-work, will cost £16 to £24 per ton.

Cost of roofing increases with span.

Wrought-iron roofing, if considered alone, may be approximately valued according to span, although every circumstance of difference must be taken into account before the rate for one roof can be exactly applied to another. Omitting very small roofs, it will be found that the framing of trussed roofs, exclusive of supports and of covering will weigh from 5 to 6 cwt. per square (measured horizontally) for spans between 40 and 50 ft.; 6 to 8 cwt. per square for spans between 50 and 60 ft.; 7 to 9 cwt. for 80 ft.; and 8 to 10 cwt. for 100 ft. The rates of cost per ton are stated above. The lightest framing is that for a covering of corrugated iron, which imposes little weight, and by its strength renders unnecessary the closer supports

Corrugated sheets.

which other materials require. The weight and cost of corrugated sheeting have already been referred to, the prices fluctuating considerably according to the current value of iron and zinc. In calculating the cost of corrugated iron for the sides of buildings, provision must be made for subsidiary framing between the columns, although this is almost entirely omitted in the case of huts or small sheds.

Iron buildings.

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The smallest iron buildings are those used as huts and cottages, and such buildings 12 ft. to 20 ft. long, 10 to 15 ft. wide, and 7 or 8 ft. high to the eaves, will cost from £20 to £25 per square, or from £25 to £60 each, including doors and windows. But prices according to area are misleading for such small buildings.

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345.

Iron bungalows.

Plain storehouses 12 ft. high to the eaves cost from £8 to £15 per square if unenclosed, and from £12 to £20 if enclosed; but from £20 to £30 per square is needed when the sides are from 12 to 20 ft. high, and numerous or strong windows, doors and ventilating fittings are required. The cost will obviously vary also according to the solidity of the supports, thickness of the sides and covering, and the general style of workmanship. Dwelling houses of iron are generally for temporary purposes, and are made light and cheap accordingly, but there are countries where strong permanent buildings can be erected with advantage, and a sufficient price paid to ensure durability and elegance. Thus for a tropical climate, like that of India and parts of South America, dwelling houses or bungalows can be built almost entirely of iron, but with thicker walls than is usual in temporary houses. That is to say, there may be an inner lining of wood with a space between it and the outer iron, which may either be left open or filled with concrete. The doors and windows would also be double. Buildings of this sort, well constructed and divided into dwelling-rooms, bed-rooms, bath-rooms, stables and servants' quarters, would cover from 40 to 60 squares, including verandah, and would cost about £50 per square, including wood and canvas lining, and all structural fittings.

Large buildings.

Markets.
See page 329.

Railway Stations.
See page 685.

It is impossible and would be misleading to lay down any rules for more important structures, such as markets and railway stations, as when a particular case arises, there are local circumstances of difference which render previous estimates inapplicable, the combination of masonry and brickwork with the ironwork, and of subsidiary buildings and accessories, increasing the difficulty of specifying the cost of ironwork alone. It is well to remember that the cost per

Causes of expense.

square of the vertical supports increases with the height, and the cost per square of roofing with the span; that buildings open at the sides are cheaper than those enclosed; simple shapes in which the parts repeat cheaper than those of irregular shape; and besides these primary points, that the kind of covering, the system of ventilation, the number of doors, windows and other accessory parts, as well as the degree of ornament, have also to be considered.

Large spans seldom needed.

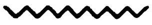
Large roofs in Paris, Chicago, and London.

Cost of large spans per square.

Gable ends of large roofs.

Example in London.

Spans larger than 100 ft. do not occur frequently, as it is generally found better when a wide enclosure is required to have two or more spans. In market buildings the spans seldom exceed 60 ft.; in railway stations the absence of intermediate columns is an advantage in the arrangement of rail lines, but except in the case of large terminal stations in cities, spans seldom exceed 100 ft. The largest span constructed up to 1888 was the St. Pancras Station, London, 240 ft.; the machinery hall built for the Paris Exhibition of 1889 has a span of 370 ft., and that at Chicago Exhibition was larger. Railway station roofs between 80 ft. and 150 ft. cost from £14 to £25 per square, including erection and covering, but beyond these spans and up to 240 ft. the cost of the station roofs erected in England has ranged from £25 to £50 per square. Under ordinary circumstances, and with iron at average rates, the cost of roofs between 150 ft. and 240 ft. span need not be more than from £20 to £35 per square, the higher cost, as just stated, having been caused by some of the following reasons: a form of construction involving much material or expensive workmanship; irregularity in the shape of the building; special expense in the covering, such as much and thick zinc, large panes of glass and strong iron sash bars; the additions of gable ends or screens; and the occurrence of high prices for material. The gable ends of the roofs over wide buildings present so large an area to the wind, that considerable ingenuity is necessary to give without undue weight or projection the strength necessary for resistance. The large buildings that have been erected in the principal cities of Europe and America, present numerous examples varying very much in the skill exhibited in this respect. The gable ends of the Olympia roof in London, previously referred to, is one of the best. In this case, the glazing was arranged in zig-zag fashion, so that the framing, of which Fig. 346 shows a sectional plan, had the appearance and strength of a ribbed or corrugated structure.



346.

Where, in wide buildings, the presence of columns is alone objected to, roof trusses of moderate span may be, as already described, supported on girders, and in some cases the roof is placed upon the lower flange of the girders so that the latter are not conspicuous from the inside of the building. There is, however, the disadvantage in this plan that part of the structure is unnecessarily exposed to the weather, the numerous small roofs hold much snow and dirt, the rain gutters are numerous, needing much attention, and in buildings of large area the lower level of the roof than is afforded by wide arched spans renders ventilation difficult.

Girders used for large spans. *See Figs.* 328, 329, 330.

The proper design for an iron roof or building and an estimate of cost can only be made on the basis of full information, which should be given on the following points:—

Designs must be based on full particulars.

The *Purpose* of the building; if with upper floors or galleries, the load to be provided for; whether for permanent or temporary use; and whether the design is to be plain or ornamental.

Purpose.

The *Dimensions* of length, width, and height, or the area required.

Dimensions.

The nature of the *Foundations*, and whether the building is to be *open* at the sides or *enclosed*, and if enclosed, whether by brickwork, wood or iron.

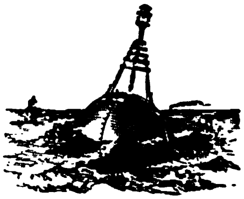
The number, description and dimension of doors, windows and other *Accessories.*

The position in which *Lighting* in the roofs is required.

The nature of the *Climate*, the kind of roof covering required, and particulars in regard to rain, snow, wind and ventilators, rain gutters and pipes.

Local particulars. *See page* 74.

[*See also* BRIDGES: MARKET-BUILDINGS: IRON *and* STEEL.]



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Mr. MATHESON has succeeded in bringing together, within a small compass, a large amount of practical information of a kind which is not generally available, and it is therefore all the more valuable.

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